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A/RIA SYSTEM
CATEGORY II FINAL TEST REPORT

July 1967

AEROSPACE INSTRUMENTATION PROGRAM OFFICE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

(Prepared under Contract No. AF 19(628)-4888 by Douglas Aircraft Modification Division, 2000 N. Memorial Drive, Tulsa, Okla. 74115.)

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FOREWORD

This report presents the results of the Category II test and evaluation of the A/RIA system, accomplished by the Douglas Aircraft Company, 2000 North Memorial Drive, Tulsa, Oklahoma 74115. The test program was authorized under Contract No. AF 19(628)-4888, with the Electronic Systems Division, Air Force Systems Command. The ESD cognizant office was the Aerospace Instrumentation Program Office (ESSIA). Tests were conducted over the period from 28 October 1966 to 25 May 1967, in accordance with the procedures established by "Category II Flight Test Procedures for A/RIA System," Douglas Aircraft Company Report No. DAC 56171, dated 15 September 1966.

This report was prepared by the Douglas Aircraft Company. An internal control document number, DEV 3796, has been assigned until approval by the Air Force approval authority.

This technical report has been reviewed and is approved.

Edgar F. Thomas
Acting Chief
435 A/B Engineering Division
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ABSTRACT

The A/RIA system is designed to provide voice and telemetry data communication with Apollo and other spacecraft, with a capability for relaying communications to the Manned Spaceflight Network and recording telemetered data on board the aircraft. The system includes a basic C-135A aircraft, modified to accept and support the electronics equipment and automatic tracking antenna required to perform the mission. The purpose of the Category II Flight Test Program was to verify that the system could acquire and track orbiting space vehicles and trajectories of ballistic missiles, using VHF, UHF, and Unified S-Band frequencies, with simultaneous recording and two-way voice link with ground stations via HF. Quantitative system testing was performed at Douglas Aircraft, Tulsa, Oklahoma; operational evaluations included coverage of Gemini XII, a Polaris ballistic missile, and simulated Apollo coverage through use of a NASA C-121 Apollo Simulator. Tests demonstrated system capability to acquire and track an Apollo vehicle at the radio horizon, a range of approximately 1200 nautical miles on VHF, with an expected data bit error of 1×10^{-4} in the data link. On Unified S-Band, the expected range is 900 nautical miles, with an expected data bit error rate of 1×10^{-4}. HF communications have been demonstrated at ranges up to 5500 nautical miles, using simplex, duplex, single sideband, independent sideband, frequency diversity, and sideband diversity. Extrapolation of the test results to the expected operational performance of the Apollo spacecraft indicates that the A/RIA system will fulfill the design requirements and perform the assigned mission.

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LIST OF ABBREVIATIONS

a/c	Aircraft
AC	Alternating Current
ACQ	Acquisition
AFB	Air Force Base
AFC	Automatic Frequency Control
AFETR	Air Force Eastern Test Range
AFLC	Air Force Logistic Command
AFSC	Air Force Systems Command
AGC	Automatic Gain Control
AGE	Aerospace Ground Equipment
ALOTS	Airborne Lightweight Optics Tracking System
AM	Amplitude Modulation
AMP	Amplifier
ANT	Antenna
APC	Automatic Phase Control
A/RIA	Apollo Range Instrumented Aircraft
ATC	Air Training Command
AUTO	Automatic
Az	Azimuth
BCD	Binary Coded Decimal
B_{LO}	Phase Lock Loop Bandwidth
BW	Bandwidth
BxR	Bendix Radio Corporation
CAPCOM	Capsule Communicator
Carr. Dev.	Carrier Deviation
Carr. Freq.	Carrier Frequency
CEC	Consolidated Electrodynamic Corporation
CEP	Circular Error Probability
CNR	Carrier-to-Noise Ratio
COMM	Communications
COR	Carrier Operated Relay
CPS	Cycles per second
CRO	Cathode Ray Oscilloscope
CRT	Cathode Ray Tube
CSM	Command Service Module
DAC	Douglas Aircraft Company
dB	Decibel
dBi	Decibel with reference to Isotropic Antenna Gain
dBm	Decibel referenced to one milliwatt
dBm/m^2	Decibels referenced to one milliwatt per square meter
dBW	Decibel referenced to one watt
dc	Direct Current
DOD	Department of Defense
Deg	Degrees
demod	Demodulator

Diff	Differential
Dopp	Doppler
DSB	Double Side Band
E	Elevation
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EQPT	Equipment
ETR	Eastern Test Range
f	Frequency
Δf	Frequency Deviation or Frequency Differential (measured)
FM	Frequency Modulation
FREQ	Frequency
FTE	Flight Test Engineer
Fwd	Forward
GFAE	Government Furnished Aircraft Equipment
GMT	Greenwich Mean Time
GSFC	Goddard Space Flight Center
GFE	Government Furnished Equipment
H	Horizontal Polarization
HF	High Frequency
Hz	Hertz
IF	Intermediate Frequency
ips	Inches per Second
IRIG	Inter-Range Instrumentation Group
ISB	Independent Sideband
JTF	Joint Test Force
KBPS	Kilobits per second
KC	Kilocycles per second
KHz	Kilo Hertz
KIAS	Knots Indicated Air Speed
KEAS	Knots Equivalent Air Speed
Kt	Knot(s)
KTAS	Knots True Air Speed
kva	Kilovolt Amperes
LH	Left Hand
LHC	Left Hand Circular Polarization
kw	Kilowatt
lo	Low
LO	Local Oscillator
ma	Milliamperes
mag	Magnetic
MAN	Manual
MC	Megacycles per second
MCC	Master Control Console
MET	Mission Elapsed Time

mils	Thousands of an inch
MHz	Mega Hertz
mm	Millimeter
MN	Mach Number
MS/AA	Manual Scan/Automatic Acquisition
MS/MA	Manual Scan/Manual Acquisition
MSC	Manned Spacecraft Center
m	Millisecond
MSFN	Manned Space Flight Network
MTS	Manual Tracking Station
NAB	National Association of Broadcasters
NAM	Nautical Air Miles
NASA	National Aeronautics and Space Administration
nm	Nautical Mile
NAUT	Nautical
NRZ	Non-Return to Zero
NRD	National Range Division
OCAMA	Oklahoma City Air Materiel Area
OD	Operations Directive
OPT	Optimum
OR	Operational Requirement
Osc	Oscillator
OSP	On-Station Position
PAM	Pulse Amplitude Modulation
P. A.	Power Amplifier
PCM	Pulse Code Modulation
PERT	Program Evaluation Review Technique
Ph	Phase
PM	Phase Modulation
PEP	Peak Envelope Power
PMEE	Prime Mission Electronics Equipment
PMEL	Precision Measurement Equipment Laboratory
POL	Petroleum, Oil, and Lubricants
Pos.	Position
PPS	Pulse Per Second
PRD	Program Requirements Document
PRI	Primary
PSRD	Program Support Requirements Document
PSTE	Personnel Subsystem Test and Evaluation
PWR or pwr	Power
Rcvr/RCVR	Receiver
Refl	Reflected
RF	Radio Frequency
RFI	Radio Frequency Interference
RH	Right Hand
RHC	Right Hand Circular Polarization

R/M	Reliability/Maintainability
RPM	Revolution per minute
RSS	Root-Sum-Square
S-IVB	Saturn Stage
SMS	Signal Monitor and Switching
SNR	Signal-to-Noise Ratio
SS/AA	Sector Scan/Automatic Acquisition
SSB	Single Side Band
SSM	System Support Manager
STD	Standard
SW	Switch(ing)
Temp	Temperature
TM/TLM	Telemetry
TR or T/R	Transmit-Receive
TRANS or XMTR	Transmitter
TRK	Tracking or Track
TSG	Time Signal Generator
TTY	Teletype
TWT	Traveling Wave Tube
UHF	Ultra High Frequency
USB	Unified S-Band
V	Vertical Polarization
V & T	Voice and Telemetry
VCO	Voltage Controlled Oscillator
VERIF	Verification
VFR	Visual Flight Rules
VHF	Very High Frequency
VOX	Voice Operated Relay
VPP	Volt(s) peak-to-peak
VSWR	Voltage Standing Wave Ratio
VTVM	Vacuum Tube Voltmeter
watts/m^2 or W/M^2	Watts per Square Meter
WB	Wideband
WPM	Words per minute
X/LHC	Horizontal or LEFT Hand Circular Polarization
Y/RHC	Vertical or RIGHT Hand Circular Polarization

SECTION I

INTRODUCTION

This document reports the results of the Category II system development test and evaluation of the A/RIA system. This system is designed to provide voice and data communications between the Apollo and other orbiting spacecraft, and ground stations of the Manned Spaceflight Network. The Category II tests were conducted in accordance with the procedures outlined in "Category II Flight Test Procedures for A/RIA System," submitted as Douglas Aircraft Company Report No. DAC 56171, dated 15 September 1966. The procedures were based on the original system test plan, submitted as a system proposal document, No. 52931, and the System Specification, submitted as Report No. 52906, Specification No. SS 100000. The Category II Test Program consisted primarily of system integration and performance evaluation. The detailed component and subsystem engineering and qualification testing was accomplished during the Category I evaluation of the system, and is reported separately.

The Category II Test Program was restricted to flight evaluation of the prime mission electronics equipment (PMEE), with the aircraft aero-structural and modification subsystem testing assigned as Category I flight test objectives. However, the Category I tasks of evaluating the navigation, electrical, and environmental control subsystems were specified tests on the Category II test aircraft, and were conducted concurrently with the Category II Test Program in the interests of conservation of flight hours, and because the subsystems are integral to the aircraft support of the PMEE installation and operation. Except for the last flight, the entire Category II Test Program was conducted without the Airborne Lightweight Optics Tracking Station (ALOTS) (a government-furnished subsystem to be available for four of the fleet of eight A/RIA aircraft). The last flight evaluated the installation and performance of the ALOTS, integrated with the PMEE and the rest of the system. The report of the ALOTS-integrated test flight is attached to this report as Appendix IX, with pertinent factors and recommendations included withing the text of the report.

Due to the complexity of the PMEE, the intra-system testing was performed by functions rather than by specific components or subsystems. In addition, the operational evaluation desired required concurrent and coordinated operation of equipment at all PMEE operator stations, rendering the functional approach the only logical method of evaluating the system. The test procedures were developed with the functional approach, and the results reported herein follow the same pattern. Each major system function is reported in its entirety, including results and recommendations which pertain to that function. The total system recommendations are summarized in Section IV. Results of the Category I flight tests and ground tests which are pertinent to the complete evaluation of the A/RIA system are included in the report where required, and the system associated tests, e. g., AGE Evaluation, Reliability and Maintainability, PSTE, Electro-Interference, and System Safety are reported in detail in Appendices IV through VIII.

Considerable re-scheduling of Category II test efforts was required by the delays in the Apollo launch schedule, with the cancellation of the February 1967 launch causing deletion of the Apollo coverage from the A/RIA Test Program. This necessitated rescheduling of the test program, and greater simulation of Apollo performance in evaluating the true capability of the A/RIA system. Results of tests conducted and simulations effected are extrapolated to the expected performance with the Apollo spacecraft; a separate section in the report is devoted to this extrapolation.

SECTION II

SUMMARY

2.1 GENERAL

The general guidelines and test objectives outlined in AFR 80-14 were utilized in the development and conduct of the A/RIA Category II System Test Program. The summary objective of the program was evaluation and demonstration of the capability of the A/RIA system to perform the total mission as outlined in the System Specification, No. SS 100000. System support capabilities were evaluated in the areas of logistics support, system reliability and maintainability, adequacy of AGE, personnel subsystems, and system safety.

2.2 TEST OBJECTIVES

The detailed objectives for the testing of each major function of the A/RIA system are enumerated in the functional description of tests performed, Section III. The specific objectives of the test and evaluation of the PMEE portion of the A/RIA system are summarized as follows:

a. Demonstration of integrated system operation as an airborne telemetry and communications relay system in the Mode I and Mode II methods of operation, required for full support of Apollo as specified by the System Specification, SS 100000.

b. Demonstration of simultaneous reception and recording of telemetry data, in both VHF and UHF bands (including Unified S-Band), during periods of uplink and downlink voice relay. Demonstration of system capability to re-transmit recorded telemetry data to the Manned Spaceflight Network (MSFN) was also required.

c. Demonstration of real-time voice communications between orbital vehicles and MSFN ground station utilizing VHF and UHF for the A/RIA-to-spacecraft link, and HF for the A/RIA-to-ground link.

d. Demonstration of simultaneous recording of voice communications timing signals, and operator voice annotation between spacecraft and ground station.

e. Demonstration of simultaneous operation of teletype and voice communications relay.

f. Demonstration of compatibility of the installation and operation of the government-furnished Airborne Lightweight Optics Tracking System (ALOTS) with the rest of the A/RIA system.

g. Demonstration of capability to receive and present to system operators standard NASA and IRIG time codes, for real-time information of range time and countdown/post-launch data.

h. Demonstration of system capability to collect telemetry data from ballistic missiles throughout trajectory to splash-down.

i. Demonstration of capability of A/RIA system to function in the environments of the NASA and DOD space control networks.

In addition to the specific PMEE subsystem test objectives, the following subsystems, functions, and aspects of the A/RIA system were evaluated and demonstrated during the Category II Test Program.

a. System reliability and maintainability

b. Personnel subsystems

c. Logistics supportability

d. System electro-interference

e. Aerospace Ground Equipment (AGE)

f. System safety

2.3 TEST RESULTS

A tabular summary of the Category II PMEE test results is given in Table I. Brief test descriptions, test goals, and test results are provided. Detailed test results and analysis of these results are included under the particular function tested in Section III of this report. All major functions were evaluated during the 27 Category II flights. The summarized test results presented in Table I and the detailed test results given in Section III were derived by comprehensive data reduction and analysis. Based upon the test results and analysis, it is concluded that the A/RIA PMEE performed satisfactorily when subjected to the test procedures defined in the "Category II Flight Test Procedures," Douglas Aircraft Company Report No. DAC 56171.

TABLE I
Category II Test Results

Test Description	Test Goal	Test Result
Acquire and Track at VHF	Acquire and Track a signal of -106.5 dBm at the antenna load (8.7 x 10^{-15} w/m^2 power density at the antenna). Reference CP100002A and A/RIA TN A0143.	Acquired and tracked at VHF at signals from -70 dBm to -106.6 dBm
Establish VHF Azimuth and Elevation Tracking Limits	Track to $\pm 100^{\circ}$ Az and $+100^{\circ}$ -30° E (Ref CP100002)	Tracked to $\pm$ 133° Az and +105° - 34° E
Establish VHF Tracking Stability Accuracy	Determine the percent of the time that VHF tracking is within $\pm$ 2° of the target	Tracked with a stability of $\pm$ 2.0° during 90% plus of the time, linear and circular polarization, against stationary and moving targets
Acquire and Track at UHF	Acquire and Track a signal of -119 dBm with Unified S-Band Config., a signal of -111.5 dBm at S-Band PCM/FM, and a signal of -106.4 dBm at L-Band PCM/FM. (Signal power at antenna load)	Acquired and tracked at Unified S-Band from -70 dBm to -119 dBm, at S-Band PCM/FM from -90 dBm to -111.5 dBm, and at L-Band PCM/FM from -94 dBm to -107 dBm
Establish UHF Azimuth and Elevation Tracking Limits	Track to $\pm$ 100° Az and + 100°, -30°E (Ref CP100002)	Tracked to $\pm$ 130° Az and $\pm$ 105° - 34° E
Establish UHF Tracking Stability	Stability of $\pm$ 1.0°	Tracked with a stability of $\pm$ 0.5° against Stationary and moving targets
Evaluate Rate Memory Operation	Keep antenna within $\pm$ 2° of target for a period of time not to exceed 10 sec. after loss of signal.	For loss of signal periods up to 9.6 secs, antenna stayed within $\pm$ 2° of target

TABLE I (Continued)

Test Description	Test Goal	Test Results
Receive and record telemetry data at VHF	Output SNR of 8.1 dB at -105.5 dBm (Apollo format). Compare computed to measure SNR SNR's at received signals from -79 dBm to -106 dBm at antenna load. (Ref A/RIA TN A0143)	Recorded Apollo format (51.2 KBPS) data at 11 dB to 13 dB SNR. Data SNR's of 7 dB to 35.5 dB were recorded at power levels from -106 dBm to -79 dBm. Also recorded 1.6 KBPS and 72 KBPS, PCM/FM, and FM/FM
Receive and record Unified S-Band telemetry data	Output SNR of 8.8 dB at -103.5 dBm at antenna load (Ref A/RIA TN A0143)	Recorded 51.2 KBPS data at 8.5 dB to 12 dB SNR. Data SNR's of 5 dB to 40.5 dB were recorded at power levels from -108 dBm to -76 dBm. Also recorded 1.6 KBPS data
Receive and record PCM/FM S-Band telemetry data	Output SNR of 3.8 dB at -104 dBm at antenna load	Received 72 KBPS data at 5 dB SNR. Data SNR's of 4 dB to 22.5 dB were measured at power levels from -105 dBm to -86 dBm
Receive and record PCM/FM L-Band telemetry data	Output SNR of 7.8 dB at -103.5 dBm at antenna load	Recorded 51.2 KBPS data at 8 dB SNR. Data SNR's of 8 dB to 21.5 dB were recorded at power levels from -103.5 dBm to -91 dBm
Receive and record VHF voice	Output SNR of 23.2 dB at -105 dBm at antenna load	Recorded 1000 Hz tone at 18 dB SNR. (4 dB of manmade noise). Voice SNR's of 11.5 dB to 25.5 dB were recorded at power levels from -113 dBm to -98 dBm
Receive and record Unified S-Band Voice	Output SNR of 18.7 dB at -103.5 dBm at antenna load	Recorded 1000 Hz tone at 20 dB SNR (average)
Relay combined VHF voice downlink downlink by HF, and HF voice uplink by VHF	Relay intelligible voice	Relayed intelligible voice downlink from Gemini, the NASA C-121 and the ground station. Relayed intelligible voice uplink from Houston, AFETR and a second A/RIA

TABLE I (Continued)

Test Description	Test Goal	Test Results
Relay combined Unified S-Band voice downlink by HF, and HF voice uplink by UHF	Relay intelligible voice	Relay intelligible voice downlink from the NASA C-121 and the ground station. Relayed intelligible voice uplink from AFETR and a second A/RIA
Establish HF voice communications	Intelligible voice links at ranges up to 5000 nm and use of all antennas	5/5 voice links established from 90 nm to 5500 nm. Transmit antennas included the left wing probe (LWP) the fin probe (FP) and the trailing wire antenna (TWA). The right wing probe (RWP) the left wing probe (LWP) and the fin probe (FP) were used for receive
Establish HF teletype Communications	A maximum of one error in each Quick Brown Fox (QBF) message	Goal met on eight Category II flights. Operated TTY in single, twin and quad diversity, with doppler correction
Dump data at UHF and VHF	Dump acceptable data. Establish data dump range	Acceptable data was dumped PCM/FM to TEL-4 (ETR). Data dump range is up to radio horizon, depending upon the ground station characteristics. The Unified S-Band 1.024-MH_2 subcarrier was not dumped.
Evaluate Timing Subsystem	Determine system accuracies	System accuracies exceeded specification. Synchronization with WWV was maintained with an average drift of 0.49 milliseconds. Time coincidence between Time Signal Generators 1 and 2 was maintained and the average drift of the secondary standard was 2.39 microseconds over a 10-minute period
Performance to Apollo Modes I and II per SS 100000	Evaluate A/RIA performance in simulated Apollo mission mode	All systems operated satisfactorily, with no apparent interaction. Two RF equipment failures occurred during the test

TABLE I (Continued)

Test Description	Test Goal	Test Results
Gemini XII Mission Coverage	Qualitatively evaluate A/RIA ability to acquire, track and receive telemetry data during predesignated orbits of a Gemini mission (VHF)	Tracked Gemini during six orbits; received and recorded VHF TLM data for six orbits; downlink voice relay on five of six orbits; uplink voice relay on two authorized orbits; full HF duplex communications established; dumped VHF TLM data to Corpus Christi. No mission analysis made (Spacecraft position, altitude, data SNR's, data bit error rate).
Ballistic Missile Mission Coverage	Evaluate A/RIA ability to acquire, track, and receive telemetry data in support of a ballistic missile mission (VHF)	Automatically tracked on VHF from mid-trajectory to splash down. Received and recorded VHF TLM data. No mission analysis made, on missile performance.

2.4 TESTS NOT PERFORMED

Eight tests were not performed during the Flight Test Program. These tests are categorized as follows:

a. Items identified in SS 100000 for flight testing but more appropriately identified for ground testing. These tests were not included in DAC 56171.

b. Tests with undefined requirements, except for verbal inputs from USAF ESD.

c. Tests outlined in DAC 56171 which were found to be infeasible or impractical to accomplish.

A listing of these tests, the requirement source, and a brief explanation of each follows:

a. Items identified in SS 100000 for flight testing but more appropriately identified for ground testing (not included in DAC 56171):

MEASURE UHF/VHF ANTENNA VSWR DURING FLIGHT

Requirement Source: SS 100000, Paragraph 4.2.1.1.2.2.1.

Explanation: The antenna VSWR is not an in-flight measurement, but rather one intended to be run as a ground test. The precise tests and measurements that can be performed on the ground cannot be duplicated in the air.

MEASURE HF VSWR DURING FLIGHT

Requirement Source: SS 100000, Paragraph 4.2.1.1.2.2.2.1.

Explanation: The equipment in the aircraft is configured for go/no-go, i.e., fault circuits which disable the transmitter when the VSWR output is greater than 1.3:1.0 (or when the output impedance is other than 50 to 52 ohms). A qualitative functional evaluation has been made of the fault circuits.

MEASURE HF RECEIVE AND TRANSMIT FREQUENCY STABILITY IN-FLIGHT

Requirement Source: SS 100000, Paragraph 4.2.1.1.2.2.2.1.

Explanation: This test was not performed in-flight because the variables involved would tend to invalidate the data. The frequency stability test requirements were verified during the Category I Ground Test under controlled conditions. Test results are documented in Test Reports BCD 58-9-10, 58-9-11, and 58-9-12.

MEASURE DATA DUMP FREQUENCY STABILITY IN-FLIGHT

Requirement Source: SS 100000, Paragraph 4. 2. 1. 1. 2. 1. 1. 4.

Explanation: This test was not performed in-flight because the variables involved would tend to invalidate the data. The frequency stability test requirements were verified during the Category I Ground Test under controlled conditions. Test results are documented in Test Reports BCD 58-5-1 and 58-5-2.

b. Items with undefined requirements, except for verbal inputs from USAF ESD.

DEMONSTRATE THAT DOWNLINK USB VOICE WILL INTERRUPT UPLINK VHF VOICE

Requirement Source: Unknown, except for verbal inputs from ESD.

Explanation: This test was not performed in flight because it was determined to be technically infeasible. Early in the Category II Test Program, the VOX units were modified to prevent the anti-VOX from having priority (ACO No. 10163). The modification precludes the possibility of either VHF or UHF (USB) downlink voice pre-empting VHF uplink transmissions. Also, uplink voice cannot pre-empt downlink voice. This modification was required to permit usable voice relay. Two basic problems existed:

(1) When transmitting VHF voice uplink, the signal from the verification probe was inadvertently feeding into channel No. 1 of the VHF voice receiver (the verification voice is fed to channel No. 2). This signal resulted in an audio output, identical to that present with a downlink voice link. The channel No. 1 output triggered the anti-VOX, disabling the uplink voice transmission.

(2) The noise level output from the VHF voice receiver (with no carrier present) was high enough to trigger the anti-VOX, preventing uplink VHF transmissions.

c. DAC 56171 tests found to be infeasible to accomplish:

DUMP VHF DATA AT 1. 6 KBPS, 51. 2 KBPS, AND 72 KBPS

Requirement Source: SS 100000, Paragraph 4. 2. 1. 1. 2. 1. 1. 4 and DAC 56171, Paragraph 7. 10.

Explanation: The data dump tests run at ETR utilized a 51. 2-KBPS bit stream only. The other bit rates would have been dumped had A/RIA flown against Apollo and recorded these data. Performance requirements were verified during the Category I Testing. Test results are documented in ESD-TR-67-293, Vol. VI (BCD 2078123), PMEE System Test Report; BCD 58-5-1, VHF Data Dump Test Report; and BCD 58-5-2, UHF Data Dump Test Report.

DUMP USB 1.024-MHz SUBCARRIER

Requirement Source: DAC 56171, Paragraph 7.10.2.

Explanation: This test was deleted once it was determined that it was technically infeasible to record and play back the subcarrier. Several ground tests proved that upon playback of the recorded subcarriers, the USB data demodulators would not lockup on the pulse trains. A technical explanation is given in Section 3.9.

EVALUATE THE PERFORMANCE OF THE PRIME FREQUENCY STANDARD IN-FLIGHT RELATIVE TO ITS PERFORMANCE ON THE GROUND

Requirement Source: DAC 56171, Paragraph 7.13.

Explanation: This test was not performed due to the inability to satisfy the test conditions at Tulsa. It was not possible to have two aircraft placed close enough together for a long enough period of time to perform the test as planned. The second aircraft was not available at the time when the primary test aircraft (A/RIA 372) was available, owing to Acceptance Tests, Milestone Tests, Category I Tests, or Air Force Familiarization Flights.

2.5 CONCLUSIONS

The Category II Flight Test results indicate that the A/RIA can support an Apollo mission and DOD ballistic missiles. Extrapolation of A/RIA performance against Gemini XII, ballistic missiles, the NASA C-121 and the A/RIA ground station indicates that the Apollo mission can be supported as predicted. Initial acquisition at the horizon is expected, and a UHF and VHF data interval beginning at 900 nautical miles should be realized. Test results show that all data and voice links are operational, and perform satisfactorily for Apollo coverage. The A/RIA tracked the Gemini XII spacecraft during six orbits, received and recorded telemetry data, performed uplink and downlink voice relay, and dumped telemetry data.

Two DOD ballistic missiles have been supported since the beginning of Category II Flight Testing. A ballistic missile launched down range from Cape Kennedy was automatically tracked on VHF from mid-trajectory to splashdown. Telemetry data were recorded in the PCM/FM and FM/FM modes. A second missile was automatically tracked on UHF (S-Band) from launch plus approximately 2 minutes to impact; VHF telemetry data were received and recorded. Only the first of these missile missions is discussed in this test report, since the second occurred after conclusion of the test program.

The 14 January 1967 Supplement to the Category II Test Procedures (DAC 56171) was prepared to relate all applicable SS 100000 specification requirements to specific test procedures. Test results prove compliance to this specification with the exception of dumping the Unified S-Band 1.-24-MHz subcarrier. This specific function is not

technically feasible within the present design of the system, although the overall function can be accomplished by dumping the Unified S-Band data in the PCM/FM mode. In addition to SS 100000 testing requirements, specified performance requirements in CEI 100002 were verified where applicable to Category II Flight Testing.

2.6 PROBLEMS ENCOUNTERED AND DESIGN CHANGES RECOMMENDED

The following system problems revealed during Category II testing, and design changes recommended, are presented in topical form. A more detailed explanation of problems and recommendations is presented in Section IV.

a. A time display is required at the navigator's position.

b. Additional intercommunications station adjacent to OA-20 and OA-21.

c. Audio tone and new intercom control at MCC position.

d. Addition of simplex capability in HF subsystem.

e. GMT timing code recorded simultaneously with data on wideband recorder.

f. Additional system operation indicators at voice/telemetry operator positions.

g. Addition of HF receiver squelch circuit.

h. Improved in-flight phasing of tracking receivers.

i. Trailing wire antenna transmissions adversely affect tracking antenna servo system.

j. No means of recording VHF voice receiver AGC's.

k. Wideband recorder level setting difficult to make.

l. High noise on VHF voice receive link when not receiving carrier.

m. HF voice combiner will not combine frequency diversity or sideband diversity signals.

n. Data dump of Unified S-Band 1.024-MHz subcarrier.

o. Additional built-in test equipment for preflight and in-flight maintenance.

p. Additional man for PMEE crew to act as Mission Director.

q. Grating over ALOTS bubble opening.

r. Additional ALOTS operator communications and life support equipment.

s. Proper grounding of aircraft during preflight and maintenance operations.

2.7 OPERATING RECOMMENDATIONS

Operational experience with A/RIA coverage of Gemini XII and ballistic missiles has demonstrated system capability for performing its design mission in the environments of both the NASA MSFN and the DOD test range network. The system is compatible from the standpoint of aircraft operations and control, as well as electronics data collection and communications. During the course of the Category II Test Program and the operational space missions flown with the A/RIA, the following system operating recommendations were developed:

a. For optimum coverage of orbiting vehicles, it is recommended that the A/RIA aircraft utilize the "button-hook" pattern throughout orbital coverage from horizon to horizon. (The nose of the A/RIA is pointed at the spacecraft throughout the pass.)

b. Ballistic missile re-entry should be covered head-on, with due respect to target antenna pattern, with the A/RIA aircraft programmed to be approximately 15 nm down-range from the target at splashdown. For total trajectory coverage, the A/RIA aircraft should be positioned laterally from the trajectory, at a distance of 15 to 50 nm at splashdown.

c. The minimum number of personnel required to perform the assigned mission of the A/RIA should be carried on actual missions. This would minimize congestion in the operating area, as well as optimize aircraft range and endurance.

d. For planning purposes, extrapolation of test data to the expected performance of the Apollo indicates that 1200 nm may be used for the range of the A/RIA system for acquisition of the spacecraft on UHF and VHF.

e. It is recommended that the tracking antenna be elevated 20°, and controlled manually, for VHF signal acquisition. Employment of autotrack should be delayed until the target reaches the elevation of 20°. Autotrack should be retained until the vehicle descends to 20° elevation, where manual track should again retain the 20° elevation. This procedure is recommended to reduce the effects of multipath on VHF.

f. Recommend fabrication and use of a ground station similar to that assembled and used at Tulsa for Category II testing, for proficiency training of AFETR A/RIA crew members, and periodic calibration of the PMEE.

g. Recommend that the trailing wire antenna not be utilized for HF transmissions while the UHF/VHF tracking antenna is being used for data collection on an actual mission, until the interference between the two subsystems is corrected through ECP 0071.

h. Recommend the ALOTS Manual Tracking Station (MTS) operator keep seat belt fastened at all times while in the MTS. Additional recommendations include lengthening of seat belt, addition of shoulder harness, and fabrication and use of tether while entering and vacating the MTS position.

i. When target acquisition is made on UHF, use should be made of sector scan with automatic acquisition. Following initial acquisition, tracking should be continued in the automatic mode.

j. To maximize the recording time, the Wideband Recorder should be operated at 60 ips for all Apollo predetection data except Unified S-Band which requires recording at 120 ips in order to achieve the higher frequency response. Recorder bandwidth of 750 KHz is obtainable at 60 ips.

k. VHF and UHF voice combiners should be used for voice relay. Separate transmitters should be used for HF voice and teletype.

l. The system preflight checkout should be closely coordinated to insure that operations such as aircraft fueling, oxygen loading, engine runs, etc., are not performed concurrently with the PMEE checkout.

m. The PMEE should never be operated without providing cooling air to the PMEE closed cooling system and the cabin.

n. Removal of the voice and telemetry operator seats will provide greatly increased working space during preflight operations and extended maintenance in the area.

o. Mission planning should insure that the A/RIA is offset from the ground track of target vehicle; a maximum elevation angle of 45° is recommended for the tracking antenna.

p. If a particular mission does not require the use of all PMEE, the spare equipment should be checked out and set up, to provide redundancy which is available in the system. Spare receivers, the second wideband recorder, and the second data multiplexer should be immediately available for in-flight patching as necessary, should the mission requirements change, or pre-set equipment malfunction.

q. The full complement of PMEE may be turned on after takeoff at any time the ram air temperature is less than $20^{o}C$. At higher temperatures, selective turn-on may be performed; close monitoring of over-temperature indicator lights must be maintained.

r. For actual missions, the PMEE pre-mission calibrations should be limited to a check of receiver dynamic range, with the detailed step calibrations reserved for the post-mission period. This would preclude the excessive use of magnetic tape for calibration and shorten the pre-mission preparation time. The problems of excessive tape use and available calibration time were encountered during preparation for coverage of the Polaris ballistic missile. (Reference paragraph 3. 12. 4. 3. 2.)

SECTION III

TEST AND EVALUATION

3.1 INTRODUCTION

The results of the Category II Flight Test and evaluation of the PMEE portion of the A/RIA system are discussed and presented in the same sequence and functional breakdown as the test program outlined in detail in the Category II Test Procedures, Douglas Aircraft Company Report No. DAC 56171. Starting with Section 3.4, each functional area of the PMEE test program will be discussed in the following sequence:

a. Tests performed

b. Test environment

c. Data collection techniques

d. System configuration of the specific tests

e. System performance (findings and conclusions)

f. Functional reliability and operability

g. Design/operational problems, including any recommendations for system improvement.

Final system recommendations will be presented in Section IV.

In order to establish the baseline for the techniques used in the collection and analysis of test data for comparison with design specifications and performance criteria, Sections 3.1 through 3.3 are used to present the vital concept of translating the system specification into a workable test program. The test concept and design will be discussed in Section 3.1.1, indicating the sources of test requirements and the goals established. Test Implementation, Section 3.1.2, covers the various techniques used in implementing the test procedures. A flow diagram outlines the operations making up a typical Category II test flight, with samples of test documentation discussed. The flight patterns used for quantitative performance data collection are discussed in Section 3.1.3; these patterns are referenced throughout the following sections on test results. Section 3.1.4 defines the several test facilities utilized during the program, with a definition of the equipment used in the Tulsa Ground Station, and the NASA C-121 Apollo Simulator. The methods used to control the electronics test environment for collection of quantitative data are detailed in Section 3.1.5, including the use of radiation pattern checks, control of signals transmitted from the ground station, and PMEE calibration techniques.

The test instrumentation employed on the aircraft, and the techniques of analyzing the data and flight test results, are discussed in Section 3. 2, with backup data presented in Appendix II. Throughout the report, only those data required to illustrate the performance of the system will be presented in the text. More detailed data, such as the Bendix Tech Notes which were utilized to establish the major parameters of the system performance, are presented in Appendix III.

Program Milestones 3 and 4 occurred during the initial stage of the Category II Test Program. Section 3. 3, devoted to a discussion of the milestone demonstrations, verifies the capability of the system to support the Apollo orbital missions. Milestone 3 demonstration was made to verify the readiness of the first aircraft for such a mission, and Milestone 4 demonstrated the capability of three aircraft to support the Apollo mission. These demonstrations, made at the beginning of the Category II program, were the initial demonstrations of system integration, but were not specific Category II test objectives.

3.1.1 Test Concept and Design

The PMEE tests planned and accomplished during the Category II Test Program were based upon the requirements of Data Item T-25-58. 0 of AFSCM 310-1 and the Category II Flight Test Procedures. The primary goal was to demonstrate that the A/RIA could support the Apollo mission during the injection, orbital, and re-entry phases, and support DOD ballistic missiles in accordance with SS 100000. During the planning stage of the Category II Test Program, it was assumed that two manned Apollo missions would occur during the time period of the program; cancellation of these missions necessarily reduced the data collected. Further, A/RIA performance against Apollo must now be extrapolated from flights against the A/RIA ground station, the NASA C-121, Gemini, and ballistic missiles.

The planning of individual tests was based upon collecting sufficient data to derive performance of the factors contributing to the primary design functions, namely: acquire and track, receive and record telemetry data, receive and record spacecraft voice, voice relay, HF voice and teletype, data dump, and timing. The number of times a test was run or a function tested was based upon two primary considerations: the commonality of the function to other tests and the requirement for sufficient data where statistical sampling techniques were necessary. The latter was involved when data analysis showed a scatter that could not be correlated with known environmental effects and classical theory, i. e., test anomalies. The level of confidence has been established by repeatability and analysis of the data. Two examples where statistical techniques proved applicable were in establishing acquisition thresholds for tracking, and determining telemetry data signal-to-noise ratios at specification levels.

As outlined in the Category II Flight Test Procedures, the degree of test complexity was increased as the program progressed. Early tests were designed to have simple objectives, with increased complexity applied after optimum test techniques were developed. The early flights were basically shakedowns with wholly qualitative goals, flown to develop the following:

a. Coordination between PMEE crew members, PMEE/flight crew members, and A/RIA/ground station operations.

b. Acceptable PMEE set-up and operating techniques.

c. Confidence that the PMEE/aircraft interface was compatible.

d. Confidence that there were no gross system inadequacies.

e. In-flight calibration techniques for important voice and telemetry parameters.

f. Acceptable techniques for the control of signal power levels, modulations, and carrier deviations.

g. Clear and concise flight cards.

h. Methods of data collection, reduction, and analysis.

Once these were developed, quantitative test data were generated for deriving system performance. Test implementation will be covered in greater detail in Section 3. 1. 2.

An important factor influencing test design was the scope of facilities available. Modulation schemes were necessarily limited by equipment in the A/RIA ground station; the NASA C-121 can only simulate Apollo modulation formats.

The scope of Category II tests was limited because of Apollo schedule slippage, to compensate for this, in part, additional ground station and C-121 flights were added to the program. Flights 21 through 31 were flown to gather quantitative data to aid in extrapolation to Apollo.

The derivation of test criteria for this program was a serious problem. It is apparent that the objective of a flight test program is to test and evaluate system/subsystem performance when operating in the dynamic environment. The results of Category I system tests should be used as the test criteria, and all flight tests designed to match these criteria. A "pass or fail" tolerance could be established, making test results clear cut. This, however, was not the situation on this program. The results of Category I system tests were not available prior to Category II, nor at the time of this report.

Test criteria/goals were established by consulting four primary sources, namely:

a. Specification SS 100000 and other top specifications deemed applicable.

b. The Category II Flight Test Procedures (DAC 56171).

c. A/RIA Technical Notes.

d. System engineers responsible for the equipment.

Where the test criteria are given in absolute numbers, they were derived from the following sources:

a. Acquire and track at VHF at 8.7 X 10^{-15} watts/m^2 (Reference CP100002A and A/RIA Tech Note A0143). This represents the calculated received signal from the Apollo CSM at a 1200 nm range.

b. Antenna tracking limits: Azimuth $\pm 100^{\circ}$, Elevation $^{+100^{\circ}}_{-30^{\circ}}$ (Reference CP100002, Paragraph 3.1.1.1.1.1.2).

c. Acquire and track at UHF at 2.3 X 10^{-14} watts/m^2 (Reference A/RIA Tech Note A0143, and CP100002A). This value is actually not an acquire and track limit, but rather a level where 51.2-KBPS Unified S-Band data are taken. The goal for acquire and track is 5.5 X 10^{-15} watts/m^2, as outlined in A/RIA Technical Note A0165.

d. Receive VHF data at received power of 1.1 X 10^{-14} watts/m^2 (Reference Tech Note A0143B) and record VHF data at 6.3 dB S+N/N (Reference Note 31, Page 333).

Note: Test goal of 8.1 dB was used on page 6 due to the A/RIA design goal of 10^{-6} BER at 51.2 KBPS as defined by ESD TWX ESSIA 30157, dated 12-27-66.

This represents the calculated received signal from the Apollo CSM at a 900 nm range, under the following conditions:

(1) Frequency: 237.8 MHz.

(2) IF bandwidth: 300 KHz or 500 KHz.

(3) Data: 51.2-KBPS, PCM/FM at a deviation of ± 125 KHz.

(4) Video bandwidth: 100 KHz.

These modulation parameters are those of the CSM VHF TLM.

e. Receive VHF data at a received power of 1.1 X 10^{-14} watts/m^2 and record at 6.5 dB S/N (Reference Note 31, Page 333). This represents the calculated received signal from the Apollo CSM at a 900 nm range, under the following conditions:

(1) Frequency: 237.8 MHz.

(2) IF bandwidth: 300 KHz or 500 KHz.

(3) Data: 1.6 KBPS, PCM/FM at a deviation of ± 125 KHz.

(4) Video bandwidth: 3 KHz.

These modulation parameters are those of the CSM VHF TLM.

f. Receive and record VHF data at received power of 1.1 X 10^{-14} watts/m^2 (Reference Category II Flight Test Procedure, DAC 56171), under the following conditions:

(1) Frequency: 253.8 MHz.

(2) IF bandwidth: 300 KHz.

(3) Data: 72 KBPS, PCM/FM at a deviation of ± 39 KHz.

(4) Video bandwidth: 100 KHz.

These modulation parameters are those of the Saturn S-IVB stage.

g. Receive and record VHF FM/FM data at a received power of 1.1 X 10^{-14} watts/m^2, under the following conditions:

(1) Frequency: 237.8 MHz.

(2) IF bandwidth: 300 KHz.

(3) Data: 20-Hz square wave frequency modulated on IRIG subcarriers frequency modulated on the carrier at a deviation of ± 125 KHz.

(4) Recorded predetection, read through a suitable filter.

These modulation parameters are those of the ballistic missile supported by A/RIA.

h. Receive and record UHF data, PCM/FM at received signal powers of 2.3 X 10^{-14} watts/m^2 and 7.6 X 10^{-13} watts/m^2 (Reference Category II Test Procedure, Paragraph 7.9.2 and A/RIA Tech Note A0143, and CP100002A) under the following conditions:

(1) Frequency: 2287.5 MHz. (Test facilities limited to this frequency.)

(2) IF bandwidth: 300 KHz.

(3) Data: 72 KBPS, PCM/FM at a deviation of ± 35 KHz.

(4) Video bandwidth: 100 KHz.

These modulation parameters are those of the Saturn S-IVB stage.

i. Receive and record Unified S-Band TLM data at 2.3 X 10^{-14} watts/m^2 (Reference A/RIA Tech Note A0143, and CP100002A). These requirements

represent calculated received signal from the Apollo CSM at a 900-nm range. The test parameters are as follows:

(1) Frequency: 2287.5 MHz.

(2) IF bandwidth: 3.3 MHz, tracking bandwidth: 1000 Hz.

(3) Data: 51.2 KBPS, phase modulated on a 1.024 MHz subcarrier. The subcarrier phase modulated on carrier (2287.5 MHz) at a deviation of 1.1 radians.

(4) Video bandwidth: 100 MHz.

These modulation parameters are those of the Apollo CSM. Other tests were run with these parameters at a level 15 dB above specification (7.6×10^{-13} watts/m^2).

j. Receive and record Unified S-Band TLM data at a received power of 3.0×10^{-15} watts/m^2 (Reference A/RIA Tech Note A0143, Amendment B), under the following conditions:

(1) Frequency: 2287.5 MHz.

(2) IF bandwidth: 3.3 MHz; tracking bandwidth: 1000 Hz.

(3) Data: 1.6 KBPS, phase modulated on a 1.024 MHz subcarrier at a PM deviation of $\pm$1.57 radians, the PM subcarrier modulated on a PM carrier (2287.5 MHz) at a PM deviation of 1.1 radians.

(4) Video bandwidth: 3 KHz.

k. Receive and record L-Band PCM/FM TLM data at a level 10 dB above tracking threshold, under the following conditions:

(1) Frequency: 1501.00 MHz.

(2) IF bandwidth: 500 KHz.

(3) Data: 51.2 KBPS, PCM/FM at a deviation of $\pm$125 KHz.

(4) Video bandwidth: 100 KHz.

l. Receive and record uncombined and polarization combined VHF voice at a signal power of 5.4×10^{-15} watts/m^2 (Reference A/RIA Tech Note A0143, Amendment B). This value represents the calculated signal received from the Apollo at 1200 nm. The test conditions were as follows:

(1) Frequency: 296.8 MHz.

(2) IF bandwidth: 30 KHz and 100 KHz.

(3) Voice: 1000 Hz tone, AM on the carrier at 85 percent modulation.

(4) Audio bandwidth: 3 KHz.

These modulation parameters are taken from the Apollo CSM VHF voice system.

m. Receive and record uncombined and polarization combined USB voice at a signal power of 2.3×10^{-14} watts/m^2 (Reference A/RIA Tech Note A0143, Amendment B), under the following conditions:

(1) Frequency: 2287.5 MHz.

(2) IF bandwidth: 3.3 MHz; tracking bandwidth: 1000 Hz.

(3) Voice: 1000 Hz tone, frequency modulated on a 1.25 MHz subcarrier at a deviation of ± 2.5 KHz, the subcarrier phase modulated on the carrier at a PM deviation of 0.54 radian (51.2 KBPS data) or 0.84 radian (1.6 KBPS data). The 7.5 KHz deviation in Tech Note A0143 is for a modulating frequency of 3 KHz.

(4) Audio bandwidth: 3 KHz.

n. Receive and transmit teletype with a maximum error rate of one error in each Quick Brown Fox message (Reference Category II Flight Test Procedure, Paragraph 7.11).

o. Maintain time synchronization with WWV ± 2 ms during flight (Reference Category II Flight Test Procedures, Paragraph 7.13.C.1).

p. Maintain time coincidence of the two time signal generators to within ± 1 μs during flight (Reference Category II Flight Test Procedure, Paragraph 7.13.C.2).

q. Maintain accuracy of the two time standards to less than ± 6 μs drift over a 10-minute period (Reference Category II Flight Test Procedure, Paragraph 7.13.C.4).

3.1.2 Test Implementation

The implementation of the tests defined in the Category II Flight Test Procedures (DAC 56171) was accomplished as planned. Several additional tests were added to gather data for extrapolation to Apollo.

Flight planning was initiated with a determination of the tests to be run by reference to the Flight Test Procedures, Specifications, Technical Notes, and past flight results. A typical Flight Planning/Implementation Sequence is shown in Figure 1. A link analysis was integral to this planning, to determine if the tests were within the scope/capability of the hardware in the A/RIA and the ground station. The analysis derived the radiated power levels for each data run. A typical link analysis is shown in Appendix III. A typical PMEE Flight Plan is also shown in Appendix III.

The next step in the sequence was the preparation of detailed test procedures, called Flight Cards, and the PMEE System Configuration Block Diagram. A set of typical Flight Cards is shown in Appendix III. An example of a Configuration Block Diagram is shown in Appendix III. The diagram gave the preflight crew the information required to properly configure the PMEE for the specific test. The block diagram technique was chosen over the patching list technique for two important reasons:

a. The diagram allowed a visual trace of the various links to insure that the intended configuration was achieved.

b. A patching error could be isolated more easily.

The block diagram listed the receiver frequencies, IF bandwidth, transmitter frequencies, etc., as well as multiplexer channel assignments, wideband (WB) recorder channel assignments, audio recorder channel assignments, and inter-system patching.

Preflight PMEE set-up and tests were usually performed the day before the flight, on the system configuration to be flown. Baseline measurements were made of the parameters to be tested in flight. A sample Preflight Special Test Request is shown in Appendix III.

A preflight briefing was conducted prior to each flight to inform the crew regarding the patterns to be flown and tests to be performed. The purpose of the flight was discussed and each of the planned tests in each data run was reviewed. Immediately after the flight, a post-flight debriefing was held to discuss flight results, based upon flight crew and equipment operator observations and records. This information was used as the basis for planning the subsequent flight(s).

At the conclusion of the debriefing a Master Flight Card was prepared, incorporating all of the data from the flight cards of the individual PMEE operators. This master card was used by the data reduction and analysis team, and provided a permanent record of operator readings and observations. A PMEE Flight Report was prepared and published giving a chronological history of PMEE operations during the flight.

3.1.3 Flight Patterns

In order that a controlled environment might be maintained throughout the entire Category II Test Program, standard flight patterns were developed that would be compatible with the different environments created by the ground station and the NASA C-121.

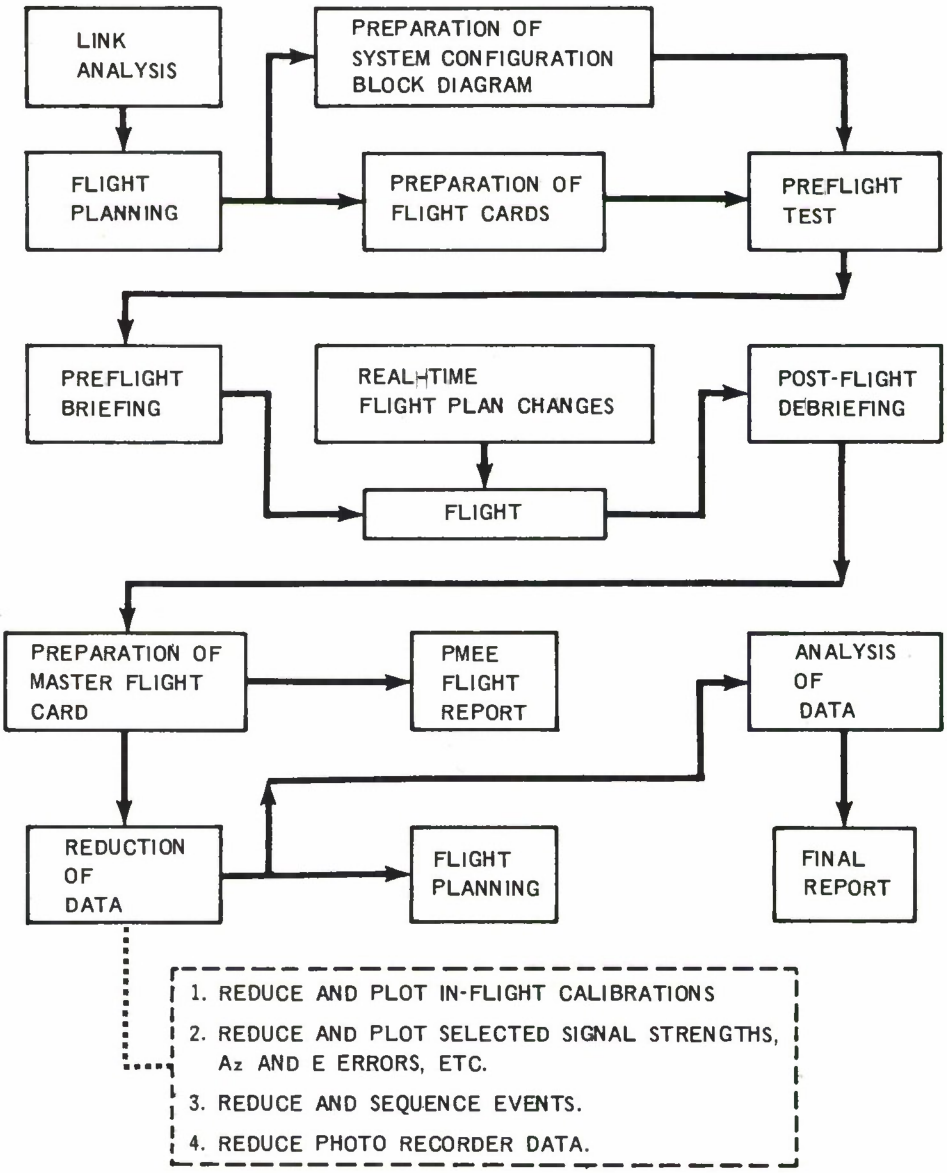


FIGURE 1. FLIGHT PLANNING IMPLEMENTATION SEQUENCE

3.1.3.1 Ground Station Flight Pattern

A basic racetrack flight pattern was flown in tests against the ground station (see Figure 2). The racetrack pattern was positioned so that the portion used for receiving and recording data (between Points 4 and 5) would always be in the main lobe structure of the VHF and UHF ground station antennas. The reference used to establish the racetrack pattern was the 219° radial of the Tulsa VORTAC; the pattern was physically positioned southwest of the ground station.

Test flights were flown as follows (refer to Figure 2): The A/RIA, flying the 219° VORTAC, was at Point 4 on the racetrack pattern 120-nm SW of the ground station; at 90-nm SW of the ground station, A/RIA was at Point 5 on the pattern. At Point 5, the pilot initiated a 23°-per-minute left turn, and maintained the turn until he was on the anti-VORTAC vector of 39°. The 39° vector was maintained for 30-nm (Point 1); at this time the pilot initiated another 23°-per-minute standard rate turn until the aircraft was once again at Point 4 on the racetrack pattern.

All tests that involved receiving and recording data from the ground station were performed between Points 4 and 5. The portion of the 23°-per-minute standard rate turn between Points 5 and 6 was used for performing antenna rate memory tests. PMEE calibrations and tests, such as cabin pressurization, PMEE cooling, etc., were performed on the back leg between Points 6 and 1. HF communication tests were usually performed while following the complete racetrack pattern.

The standard racetrack pattern was modified on two occasions in order to perform special antenna tests:

a. Figure 3 represents the pattern modification used for determining the A/RIA antenna azimuth tracking limits; the only difference is that the pattern was flown at approximately 90° to the standard pattern headings.

b. Figure 4 represents the pattern modification used for evaluating the A/RIA antenna at high azimuth tracking rates, determining the amount of ellipticity present with the VHF receive system in the circular polarization mode, and the vertical-to-horizontal sum channel power level difference (degree of cross polarization) with the A/RIA VHF receive system in the linear polarization mode.

3.1.3.2 NASA C-121/A/RIA Flight Patterns

Two flight patterns were used in tests against the C-121. The flight patterns were designed to compensate for the limited altitude and speed capabilities of the C-121 as compared to the A/RIA C-135. Figure 5 represents the flight pattern used for Flights 6 and 13. On these two flights the C-121 was operated at an altitude of 20,000 feet T, TC and a cruising speed of 250 knots. The A/RIA C-135 flew at a true altitude of 35,000 feet and a cruising speed of 400 knots. The UHF signal levels were marginal because the C-121 antennas were located on the bottom of the aircraft.

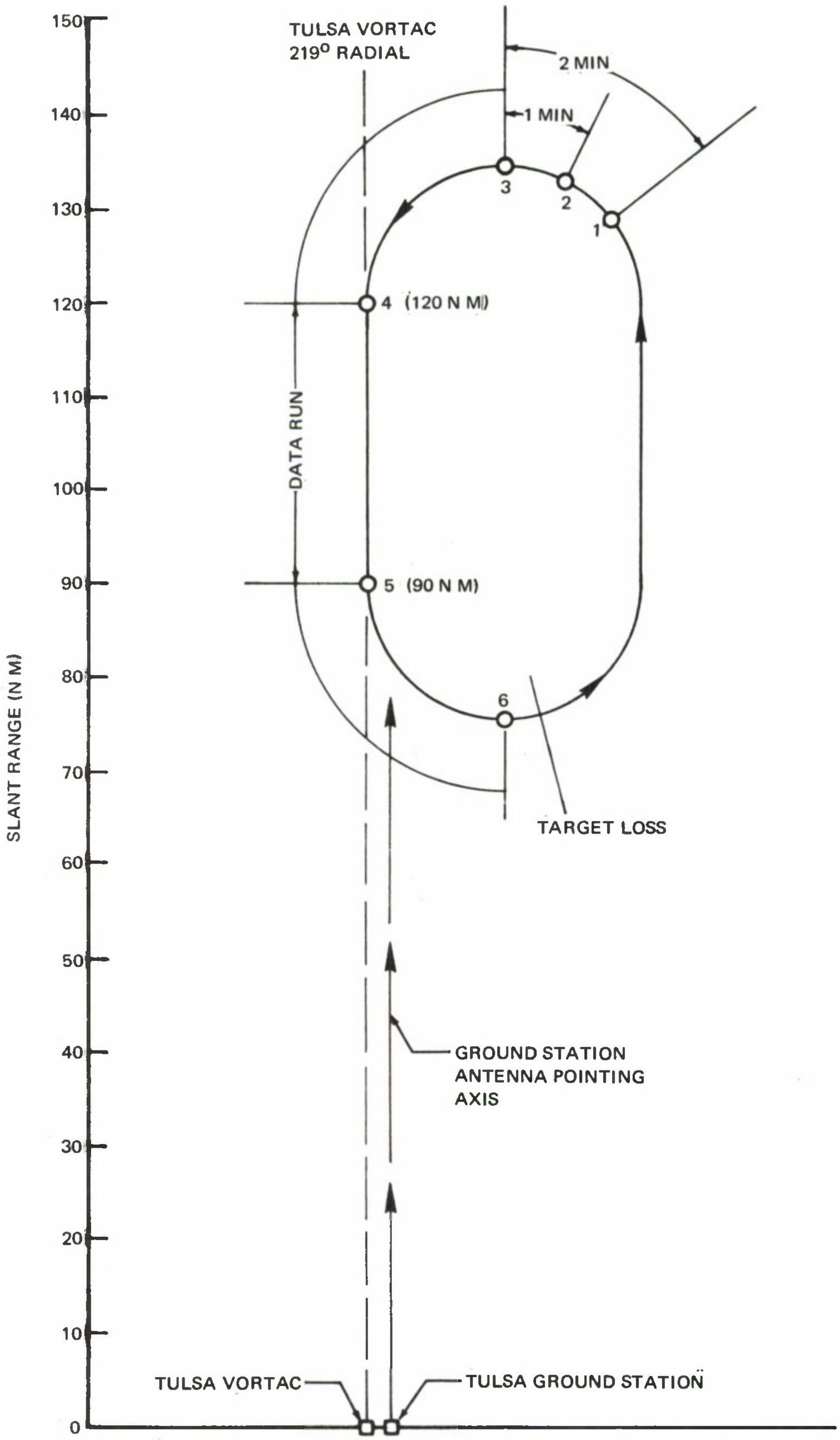


FIGURE 2. TULSA GROUND STATION STANDARD FLIGHT PATTERN

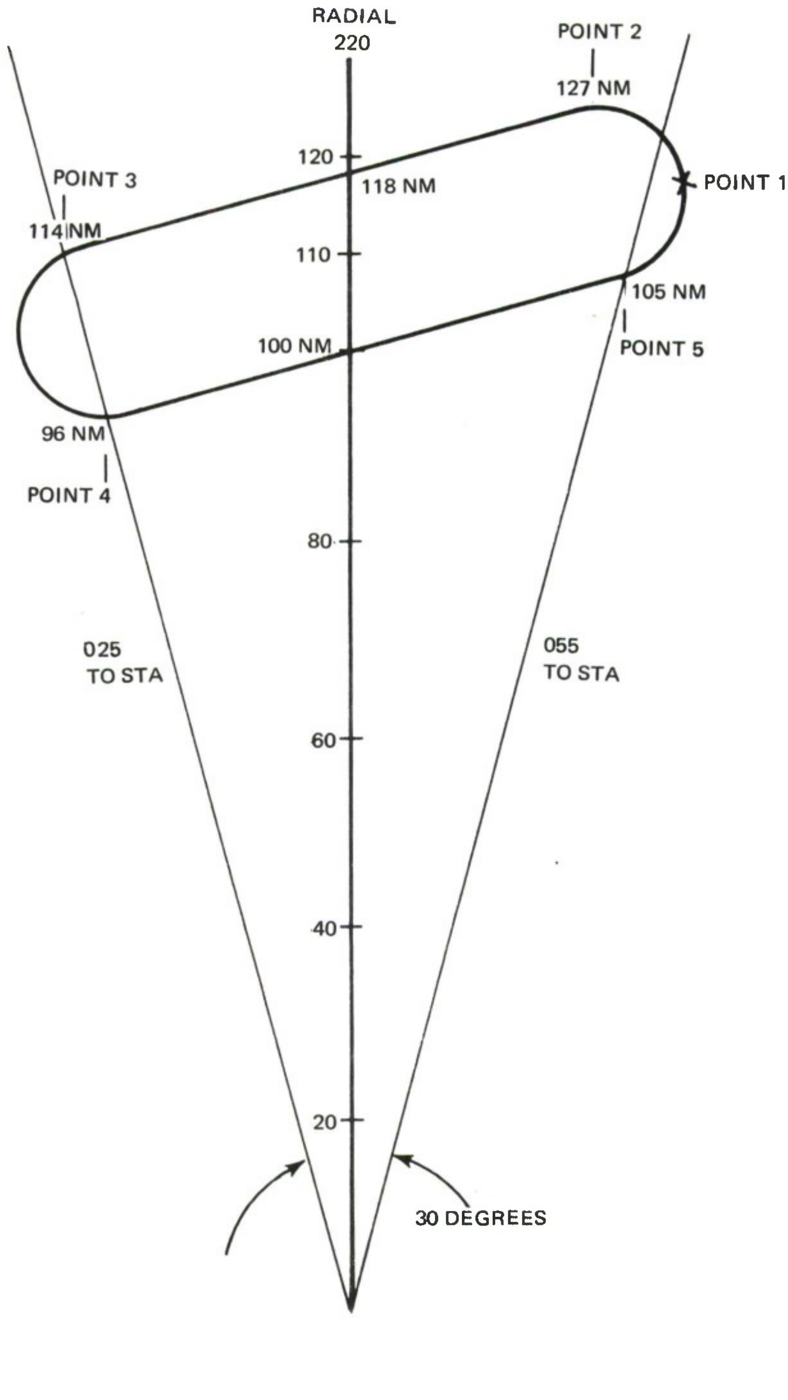


FIGURE 3. TULSA GROUND STATION CROSS-TRACK FLIGHT PATTERN

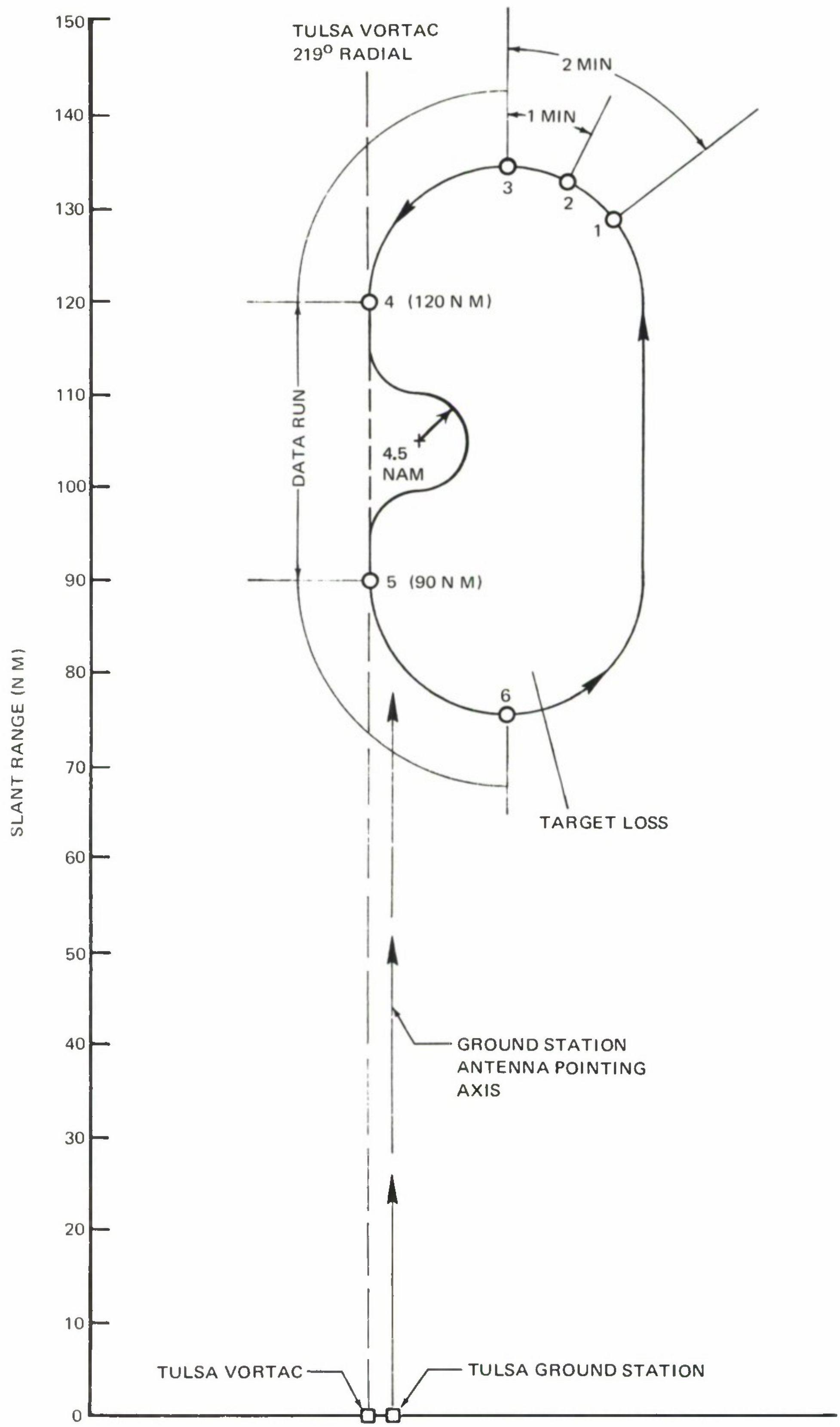


FIGURE 4. TULSA GROUND STATION SPECIAL FLIGHT PATTERN

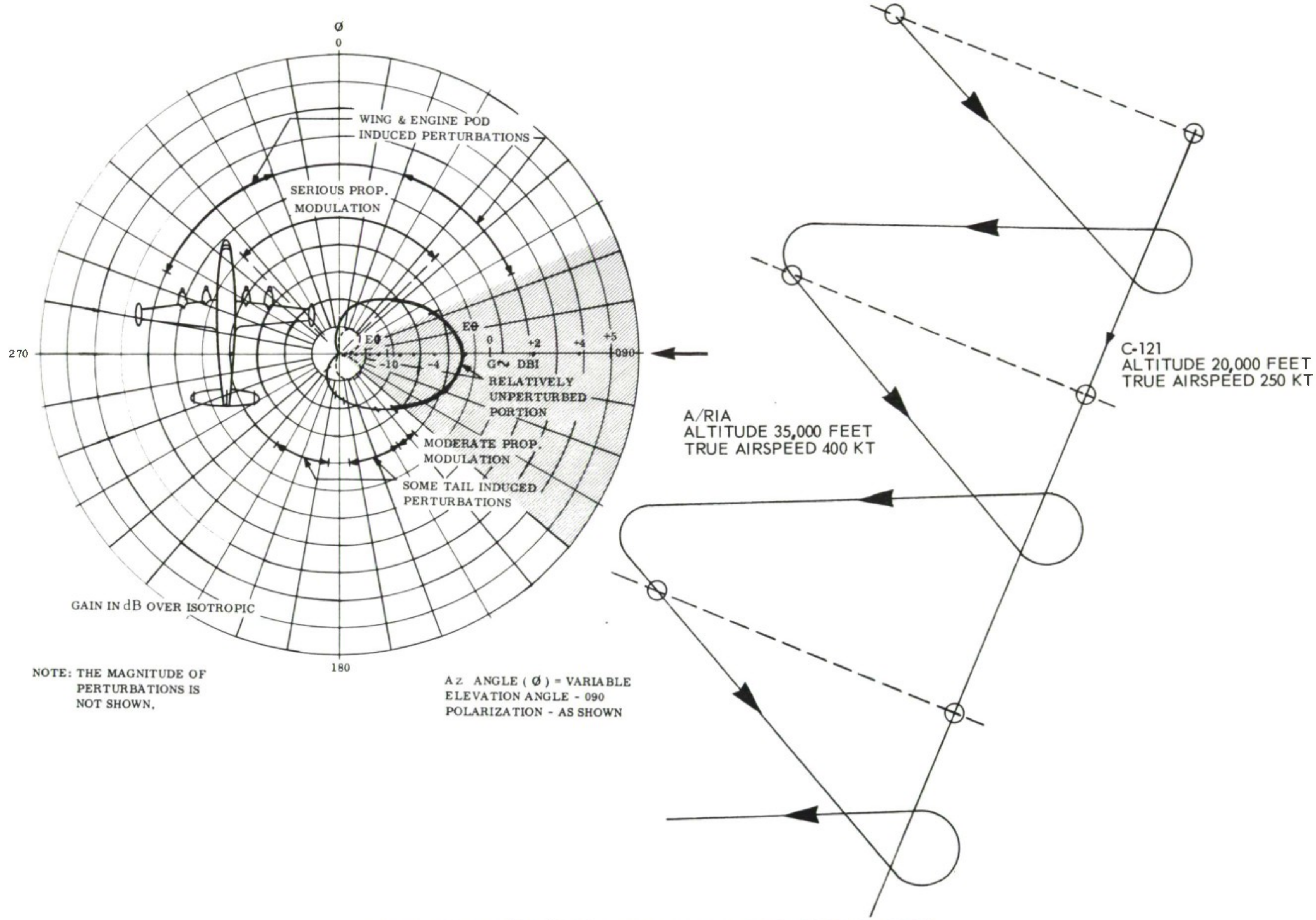


FIGURE 5. A/RIA/C-121 FLIGHTS 6 AND 13 PATTERN

Figure 6 represents the flight pattern used for Flights 29 and 30. The C-121 flew at a true altitude 20, 000 feet at a speed of 250 knots, and the A/RIA C-135 flew at 18, 000 feet. By this time in the program, the A/RIA had been qualified to fly below 35, 000 feet.

3.1.4 Test Facilities

During the Category II test phase there were four separate test facilities used to accomplish the A/RIA PMEE system performance tests.

3.1.4.1 Tulsa Ground Station

The ground station provided a stable, controlled, fixed-position environment for tests where precise signal level measurements were required and where test results could be repeated. The ground station provided the following test links:

a. VHF communications between the A/RIA Mission Control Coordinator and the Ground Station Operator.

b. VHF communications between the A/RIA Pilot/Test Engineer and the Ground Station Operator.

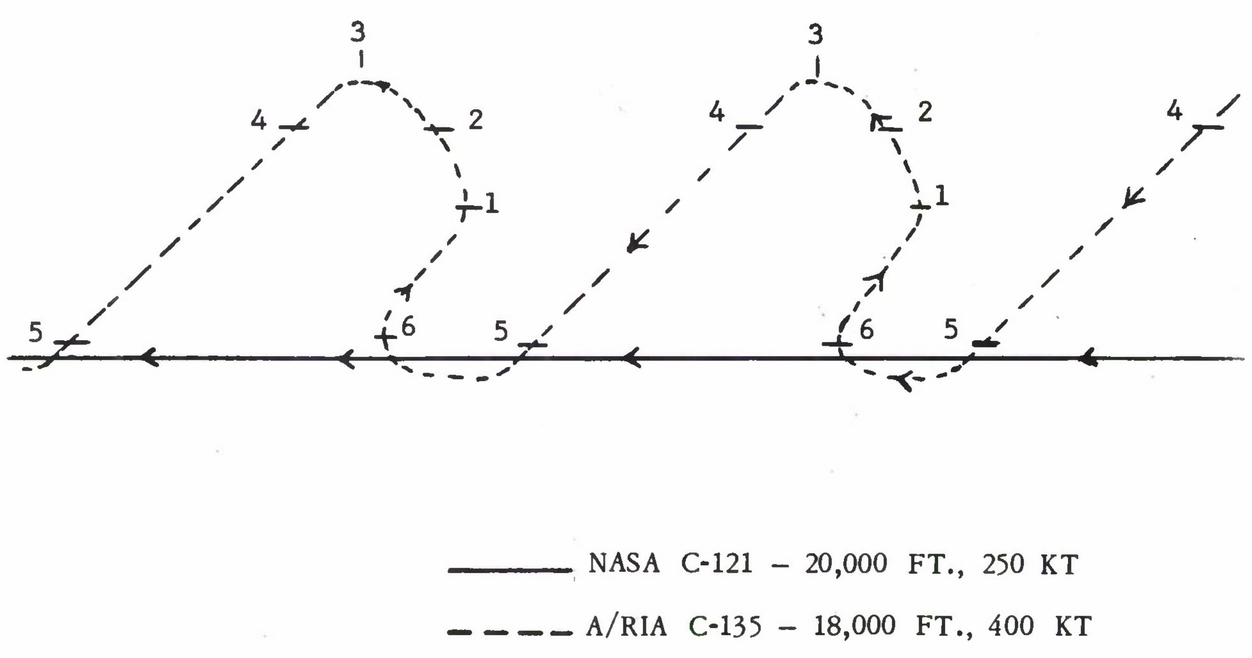


FIGURE 6. A/RIA/C-121 FLIGHTS 29 AND 30 PATTERN

c. VHF PCM/FM data.

d. VHF PCM/FM/FM data.

e. VHF AM voice (controlled signal level).

f. USB PCM/PM/PM data.

g. USB FM/PM voice.

h. USB PM emergency voice.

i. UHF PCM/FM data.

j. L-Band PCM/FM data.

k. USB transponder.

   (1) The transponder provided practice in scanning for and locking up an Apollo-type transponder.

   (2) Capable of transmitting and receiving USB voice and data.

Figure 7 is an overall block diagram of the Tulsa Ground Station test facility.

3.1.4.2 NASA C-121 Apollo Simulator

The C-121 provided an operational environment more closely approximating the conditions expected during an actual Apollo mission. The C-121 Apollo Simulator was capable of providing the following test links:

a. Two-way USB voice communication link.

b. Two-way VHF voice communication link.

c. VHF PCM/FM data.

d. USB PCM/PM/PM data.

e. USB Apollo-type transponder system.

Also, the C-121 provided a moving target for acquisition and tracking tests. Figure 8 is an overall block diagram of the C-121 electronic equipment configuration. Figure 9 shows the NASA C-121 used during the Category II Flight Test Program.

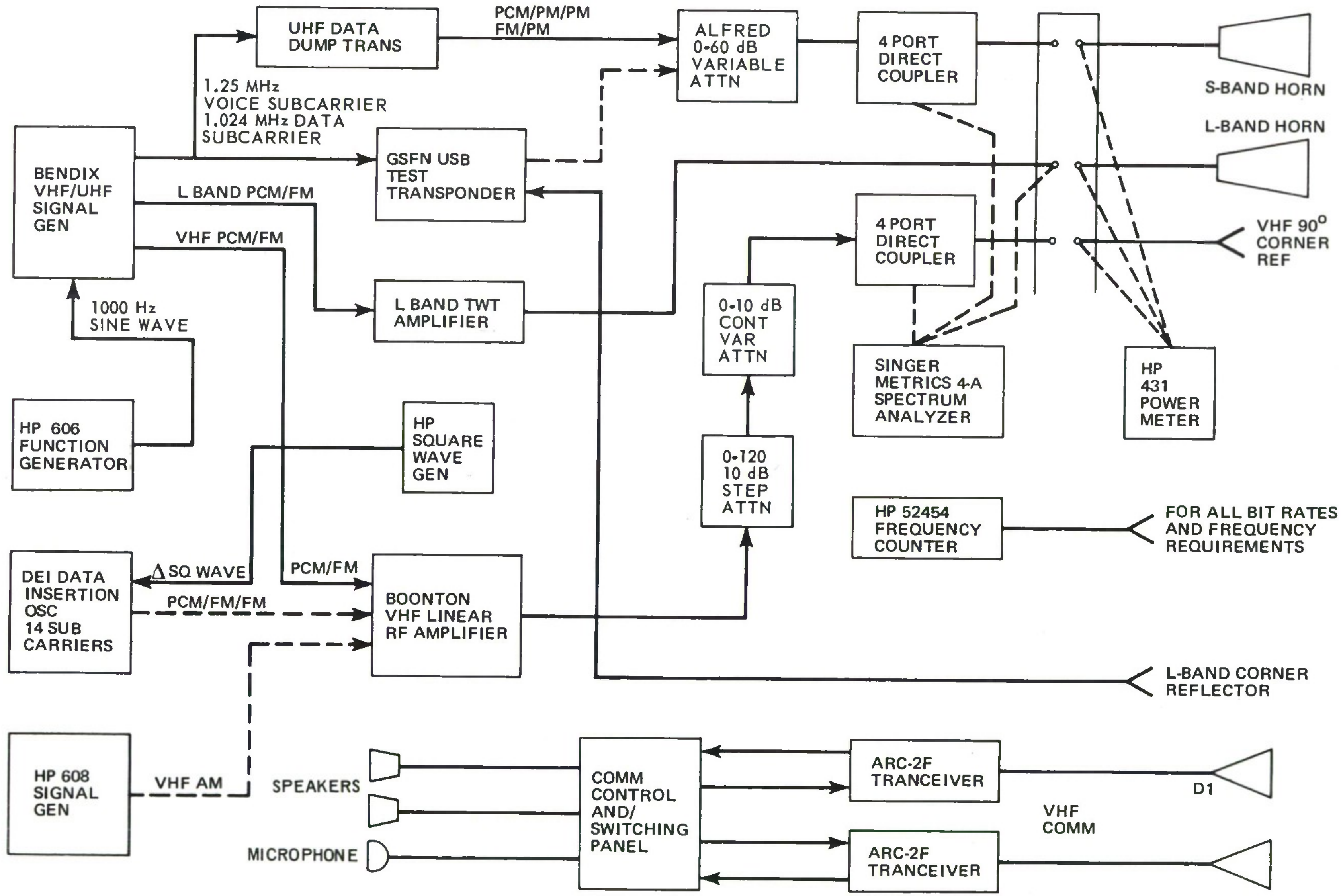


FIGURE 7. TULSA GROUND STATION OVERALL BLOCK DIAGRAM

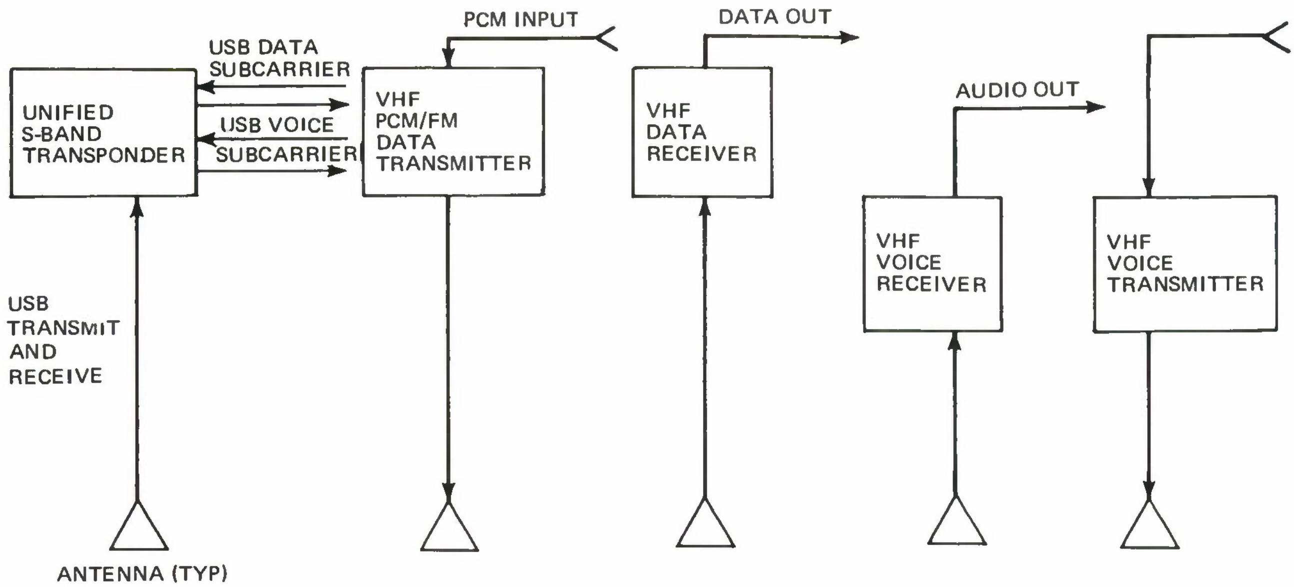


FIGURE 8. NASA C-121 APOLLO SIMULATOR AIRCRAFT BLOCK DIAGRAM

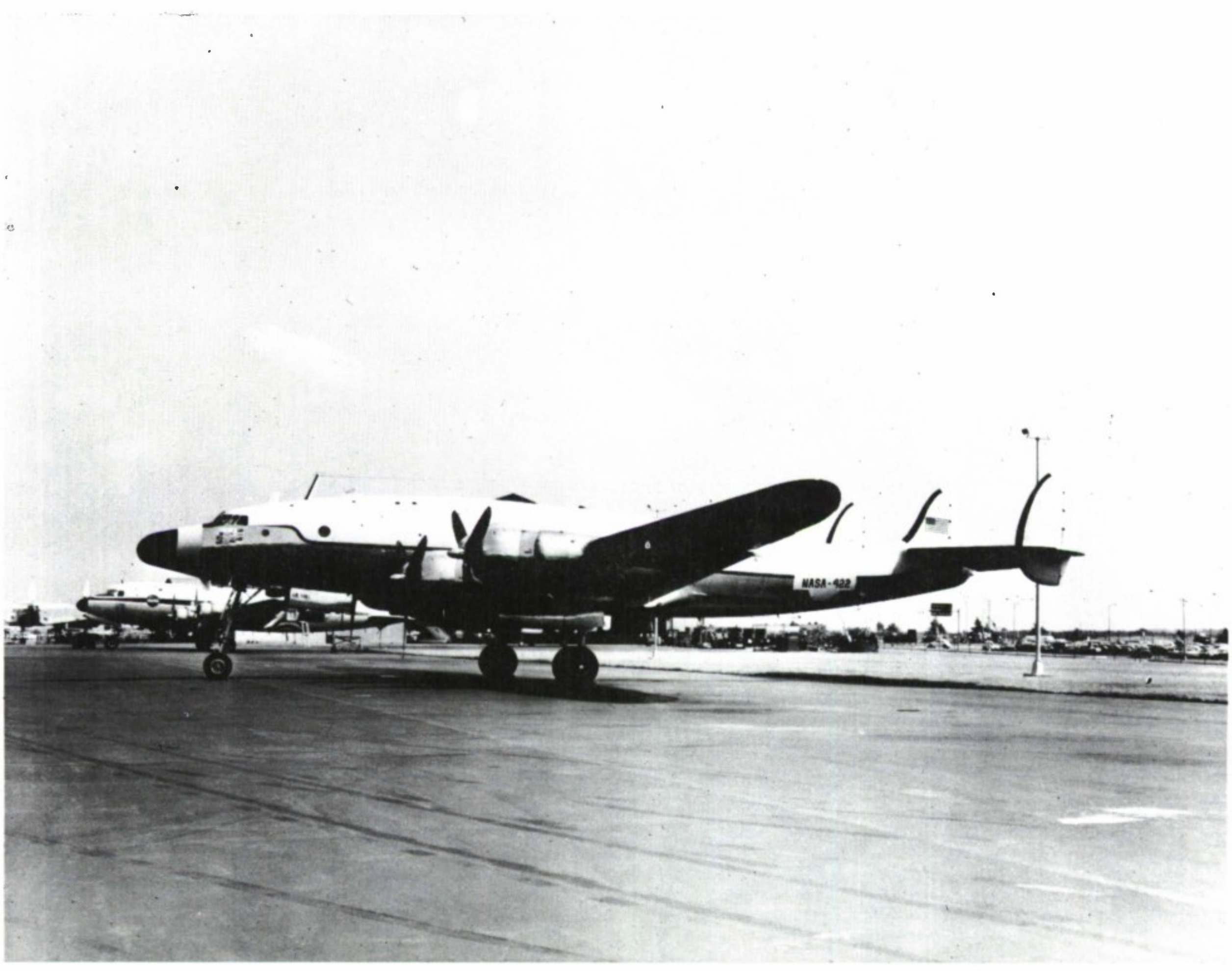


FIGURE 9. NASA C-121 APOLLO SIMULATOR AIRCRAFT

3.1.4.3 Ballistic Missile Mission

On 2 March 1967, A/RIA 372 supported a ballistic missile flight. The ballistic missile provided a means of obtaining data on the performance of the A/RIA in a dynamic signal environment. The details of the missile instrumentation/telemetry system are classified.

3.1.4.4 Gemini-XII Mission

A/RIA 372 was flown against Gemini-XII on 12 November and 14 November 1966. The flights provided an opportunity for evaluating the A/RIA PMEE under actual spacecraft environment. No information was made available on the Gemini hardware.

3.1.5 Signal Control and Calibration

3.1.5.1 Ground Station Antenna Radiation Pattern Check

A radiation pattern test run was made at the beginning and end of each ground station test flight to insure that all tests were performed within the main lobe structures of the VHF and UHF ground station antennas (see Figure 10). The ground station VHF and UHF antennas were set to a height that would position the first radiation pattern null at 59-nm from the ground station with the A/RIA aircraft at an altitude of 35,700 feet MSL. Since changes in temperature, weather conditions and atmospherics will affect the antenna lobe structures causing the null positions to shift, the first radiation pattern check was made with the antennas set to the calculated heights of 5.5 wavelengths.

The nulls were determined by recording VHF and UHF AGC readings in A/RIA at 15-second intervals. Once the nulls were determined, the navigator marked his map and calculated the exact null positions relative to the ground station. The null locations were relayed to the ground station operator, and the VHF and/or UHF antenna height was adjusted, as necessary, to position the pattern null at 59-nm from the ground station.

A second radiation pattern check was made at the completion of the test flight to insure that the VHF and/or UHF antenna pattern nulls had remained at 59 $\pm$ 5-nm. The antenna radiation pattern checks, in addition to establishing the exact location of the main lobes of the antennas, provided a means of determining if there were any "scalloping" or other lobe perturbations present that would affect the data. Lobe variations, if present, were considered when reducing AGC for signal strength determination from the oscillograph records. All tests were performed between Points 4 and 5 on the antenna pattern (see Figure 10).

3.1.5.2 Control of Ground Station Test Parameters

All test parameters such as FM, PM, and AM requirements, bit rates, frequencies, and signal power levels were set and monitored with calibrated test equipment. Cable

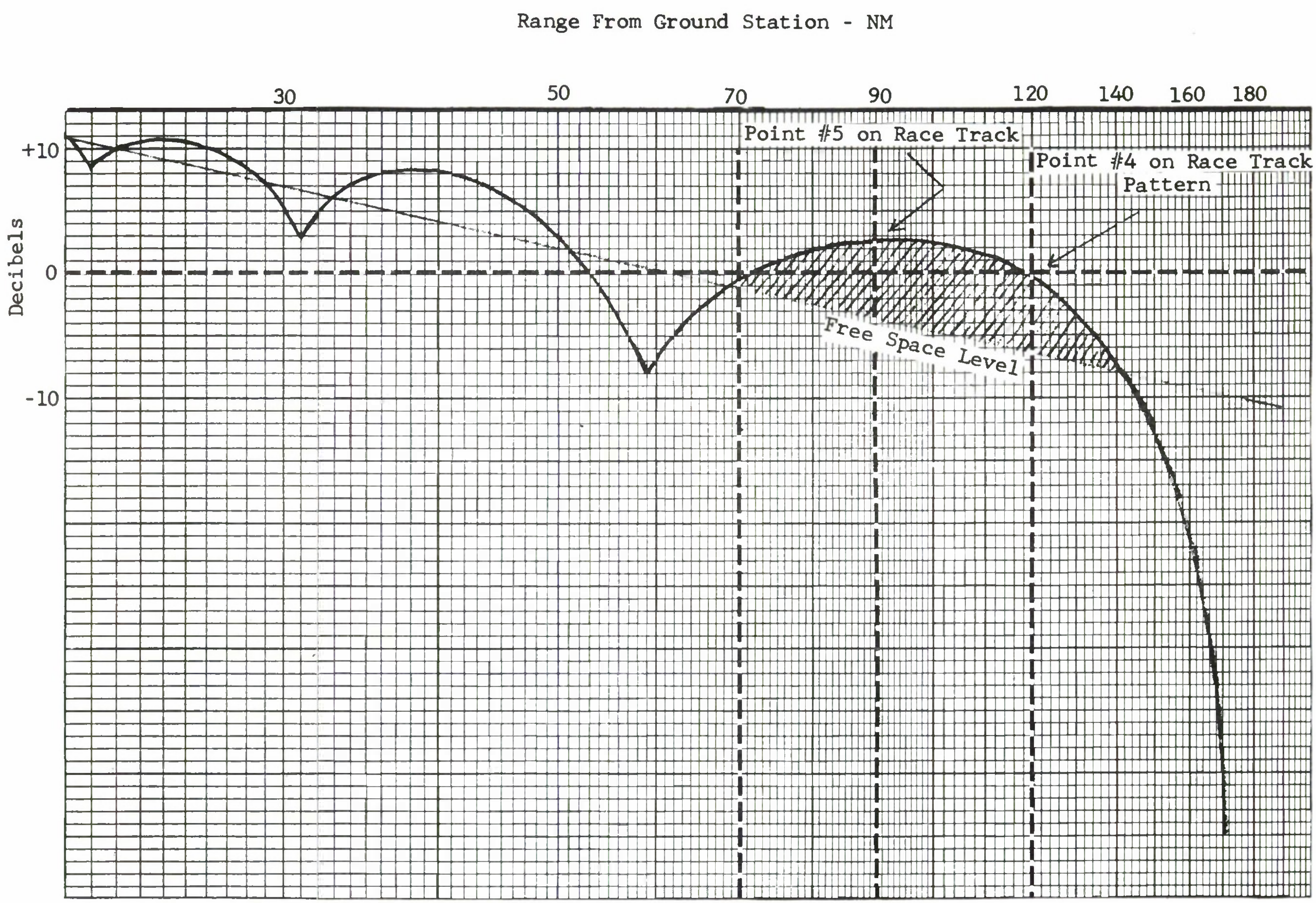


FIGURE 10. TULSA GROUND STATION PROPAGATION PATTERN

loss and antenna VSWR were measured before each test flight. Test equipment calibrations were maintained current throughout the Category II Test Program.

The signal power levels required for each test were determined by link analysis and referenced to the ground station patch panel and the A/RIA directional coupler. Following is a sample of the link analysis technique used to determine the signal power levels required at the ground station patch panel to yield a specified signal level at the A/RIA VHF feed system directional coupler:

Requirement: Radiate PCM/FM at a carrier frequency of 237.8 MHz, deviated ± 125 KHz at 51.2 KBPS to produce a power density of 8.7×10^{-15} watts/m^2 outside the A/RIA antenna.

watts/m^2 to dBm/m^2

$$8.7 \times 10^{-15} = \left[-150 + (10 \log 8.7)\right] + 30$$
$$= \left[-150 + 10(0.9395)\right] + 30$$
$$= (-150 + 9.395) + 30$$
$$= -140.6 + 30$$
$$= -110.6 \text{ dBm/m}^2 \text{ outside the A/RIA antenna}$$

dBm at directional coupler = dBm/m^2 + C_a - L_u

dBm/m^2 = -110.6

C_a = (Captive area of A/RIA antenna at 237.8 MHz) = +4.1

L_u = (Loss between A/RIA antenna and directional coupler) = -1.9

$$= -110.6 + 4.1 - 1.9$$
$$= -108.4 \text{ dBm}$$

Solving for the required signal power level at the ground station patch panel output:

$-P_{dc}$	(Power level at the A/RIA directional couplet, dBm)	-108.4
$-L_t$	(Loss between ground station patch panel and antenna)	- 2.3
G_t	(Gain of ground station VHF antenna)	+ 10.0
$-L_s$	(Space loss for 237.8 MHz at 70-nm)	-122.3
$-L_o$	(Polarization loss, circular to linear)	- 4.1
G_T	(A/RIA antenna gain, VHF)	+ 13.0
$-L_u$	(Loss between A/RIA antenna and directional coupler)	- 1.9
P_t	(Power level at ground station patch panel)	

$$P_{dc} = (P_t - L_t) + G_t - L_s - L_o + G_T - L_u$$
$$-108.4 = P_t - 2.3 + 10 - 122.3 - 4.1 + 13 - 1.9$$
$$-108.4 = P_t - 130.6 + 23$$
$$-108.4 = P_t - 107.6$$
$$-P_t = 108.4 - 107.6$$
$$-P_t = 0.8$$
$$P_t = -0.8 \text{ dBm signal power level at the ground station patch panel.}$$

The calculated signal power level was set by connecting the HP 431B power meter to the VHF transmitter output jack on the patch panel and adjusting the VHF variable attenuator (located between the VHF transmitter output and the patch panel) for a -0.8-dBm reading on the power meter.

Link analysis for all tests was computed in the same manner, substituting the parameters unique to each frequency requirement. These parameters are listed in Table II.

TABLE II

Link Analysis Parameters

Frequency (MHz)	$-L_t$ (dB)	$+G_t$ (dB)	$-L_s$	$+G_T$ (dB)	$-L_u$ (dB)	$+C_a$ (dB)
237.8	2.3	10	122.302	13	1.9	4.1
296.8	2.7	10.5	124.154	13	1.9	2.1
2287.5	5.1	16.2	141.936	30.6	2.1	2.6

The 70-nm range used for all link analyses was chosen because at this range the lobe and free space loss curves cross, (see Figure 10) simplifying the calculation. Also, the absolute signal level at 70-nm is the same as that expected at 120-nm (Point 4 on the racetrack pattern). The only signal level change expected between Points 4 and 5 is +3 dB (reference Figure 11).

The bit rates and frequency requirements were set and monitored with a HP 5245L frequency counter. Modulation requirements were set and monitored with a Singer Metrics Model 4-a spectrum analyzer.

a. VHF PCM/FM Link

The VHF PCM/FM signals consisted of the VHF FM carrier pulse-modulated by a bit stream (square wave) from the VHF/UHF signal generator. Figure 12 is a block diagram of the VHF PCM/FM configuration. The deviation requirements at specified bit rates were set by the carrier suppression method.

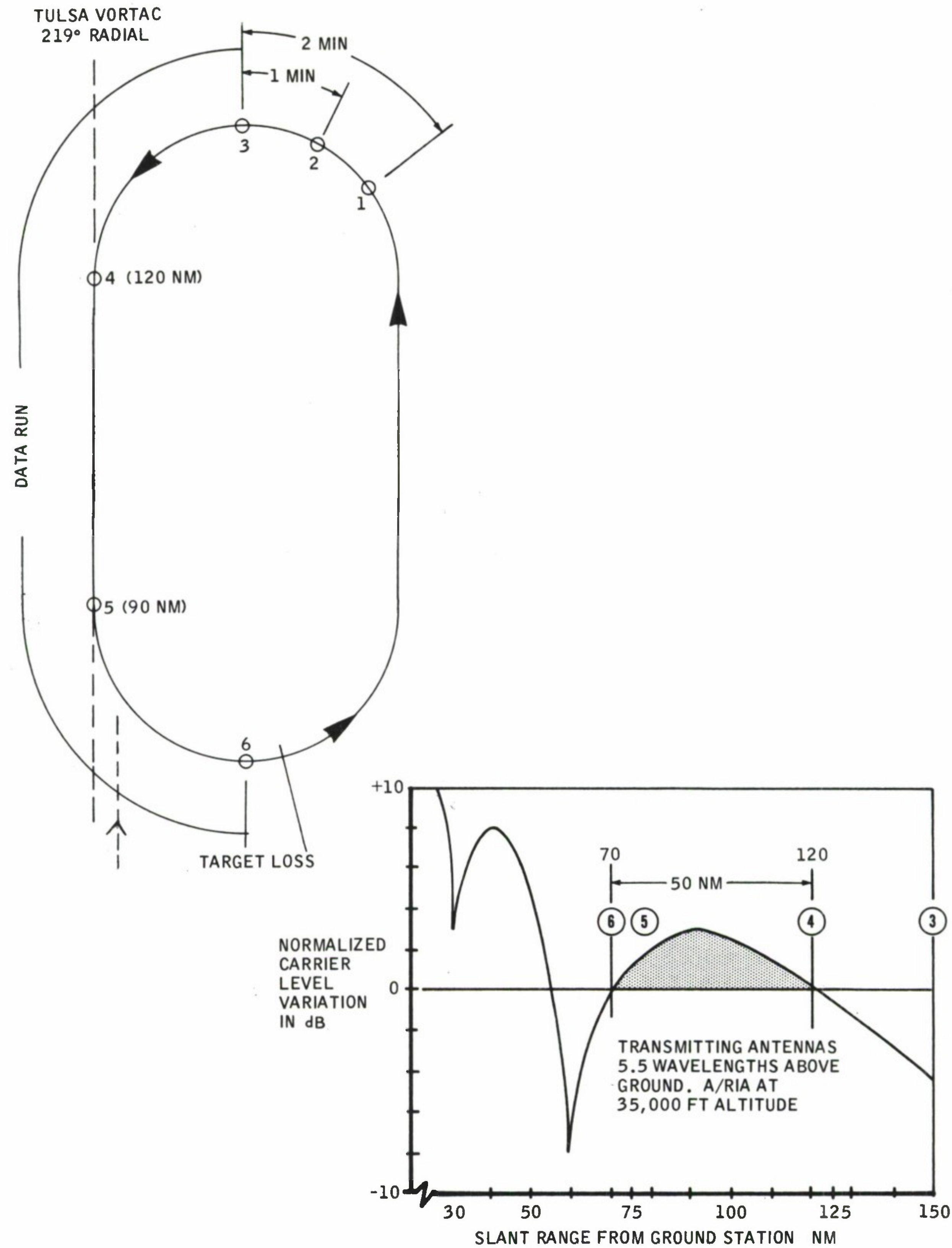


FIGURE 11. TULSA GROUND STATION FLIGHT AND PROPAGATION PATTERN DIAGRAM

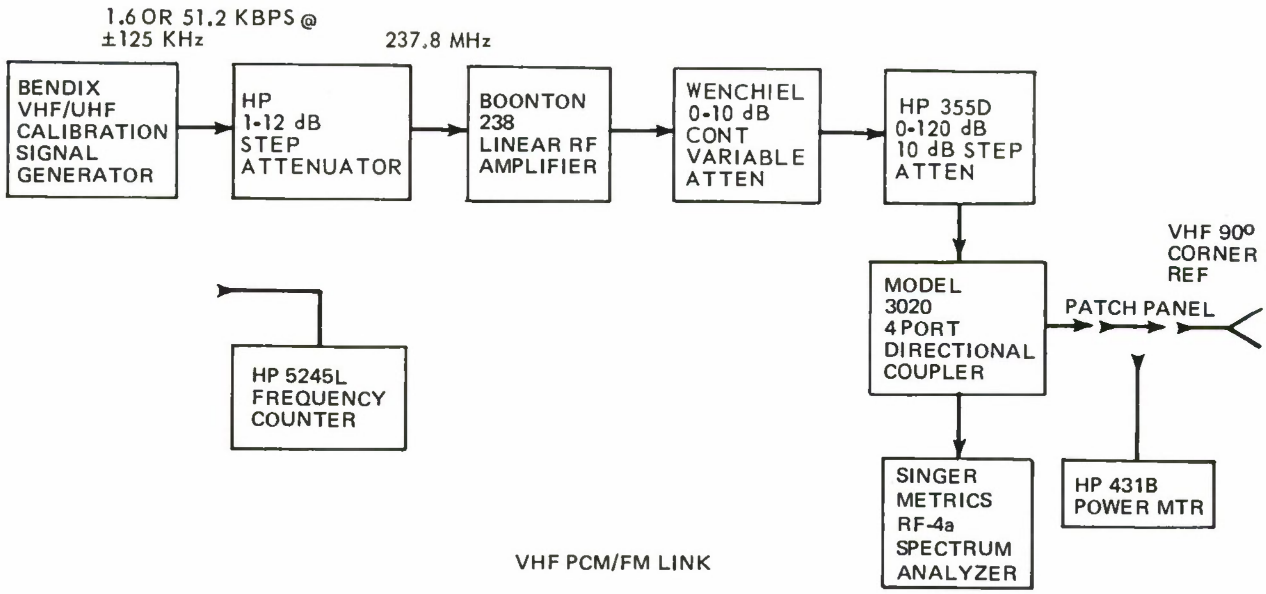


FIGURE 12. TULSA GROUND STATION VHF PCM/FM LINK BLOCK DIAGRAM

b. VHF AM Voice Link (296. 8 MHz)

The VHF AM voice signal consisted of a 296. 8-MHz carrier from a HP 608C signal generator, externally modulated 85-percent by a 1000-Hz sine wave from the HP 202A function generator. The modulated carrier output of the HP 608C was then amplified by the Boonton 238 linear amplifier (reference Figure 13.) Amplitude modulation percentage was set with the amplitude modulation meter on the HP 608C signal generator.

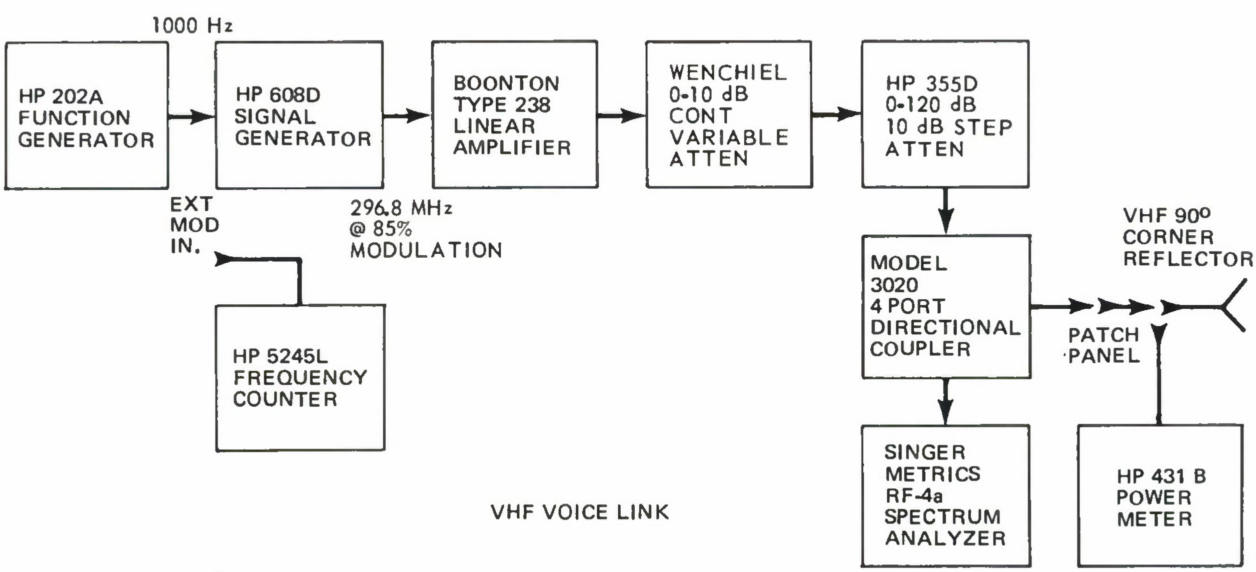


FIGURE 13. TULSA GROUND STATION VHF VOICE LINK BLOCK DIAGRAM

c. USB Tests Utilizing the UHF Data Dump Transmitter

The USB format tests consisted of a 1.25-MHz voice subcarrier frequency modulated by a 1000-Hz tone and a 1.024-MHz subcarrier bi-phase modulated by a bit stream (square wave). The two subcarriers phase modulated the data dump transmitter carrier (see Figure 14). The phase modulation and frequency modulation formats for each test requirement were set by the carrier suppression method (Reference NOTE 2, page 323).

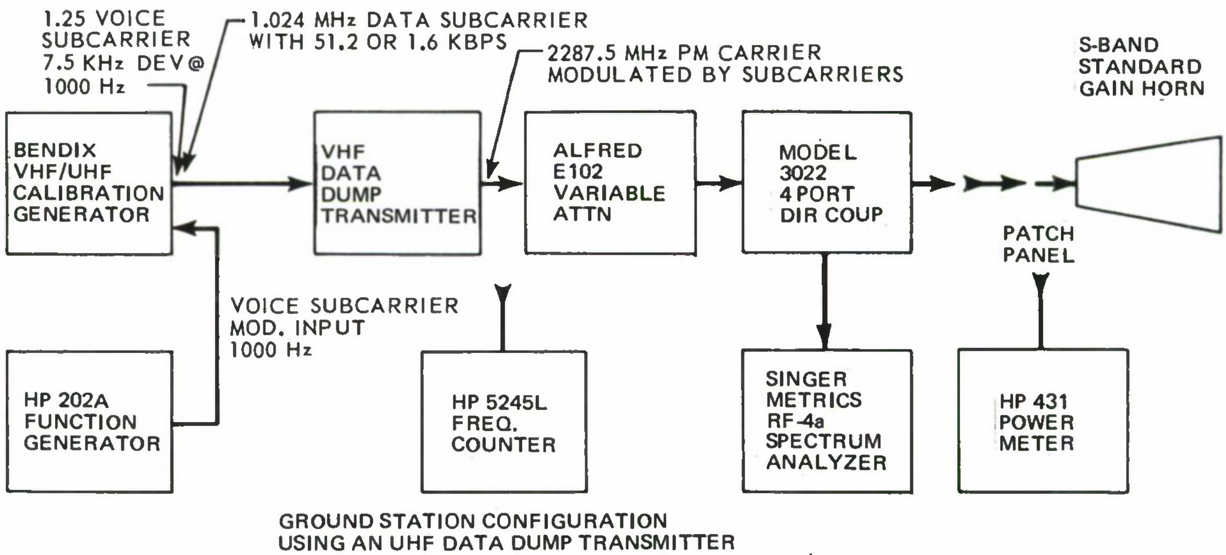


FIGURE 14. DATA DUMP TRANSMITTER USB DATA AND VOICE LINK

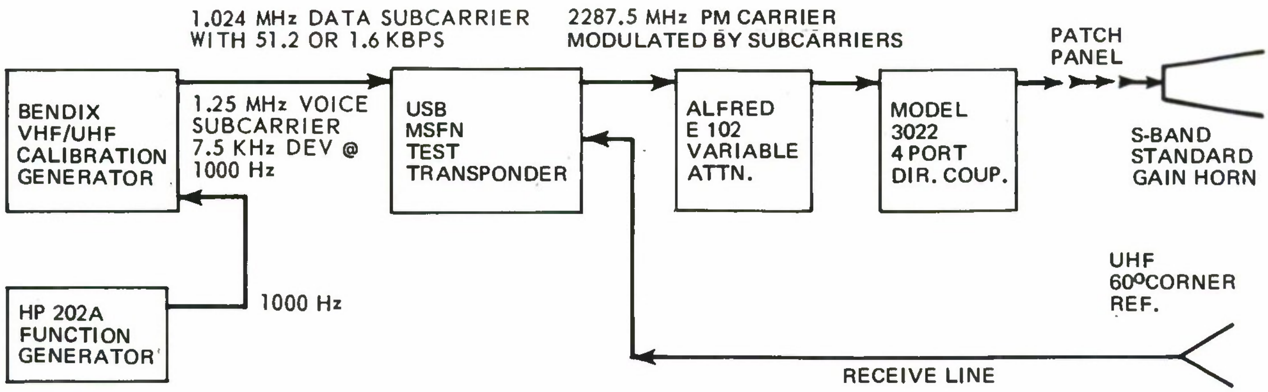
d. Unified S-Band Tests Utilizing the GSFN Test Transponder

The Unified S-Band (USB) signals used to modulate the test transponder were identical to those used with the data dump transmitter, and FM and PM requirements were set up by the same method.

Several modifications were made to the test transponder to make it compatible with the ground station test requirements. A description follows:

The normal power output level of the transmitter portion of the transponder was -20 dBm. The output power was increased 3 dB by bypassing the T/R diplexer. This modification necessitated using separate receive and transmit antennas. An additional 10 dB of attenuation was removed by bypassing an output hybrid and a 7-dB fixed pad located between the transmitter X30 multiplier and the output bandpass filter. The variable attenuator controlling the transmitter output was bypassed, eliminating 18-dB insertion loss. These modifications brought the power level output up to +11 dBm, which was adequate for test purposes.

A UHF 60° corner reflector for 2106.5 MHz was designed and fabricated for use with the transponder receiver. Figure 15 is a block diagram of the ground station configuration using the transponder.



GROUND STATION CONFIGURATION
USING THE MSFN TEST TRANSPONDER

FIGURE 15. TEST TRANSPONDER DATA AND VOICE LINK

e. UHF PCM/FM Data Link Test

The UHF PCM/FM test signal consisted of the UHF 2287.5-MHz FM carrier of the data dump transmitter pulse modulated by a bit stream (square wave) from the HP 211A square wave generator (see Figure 16).

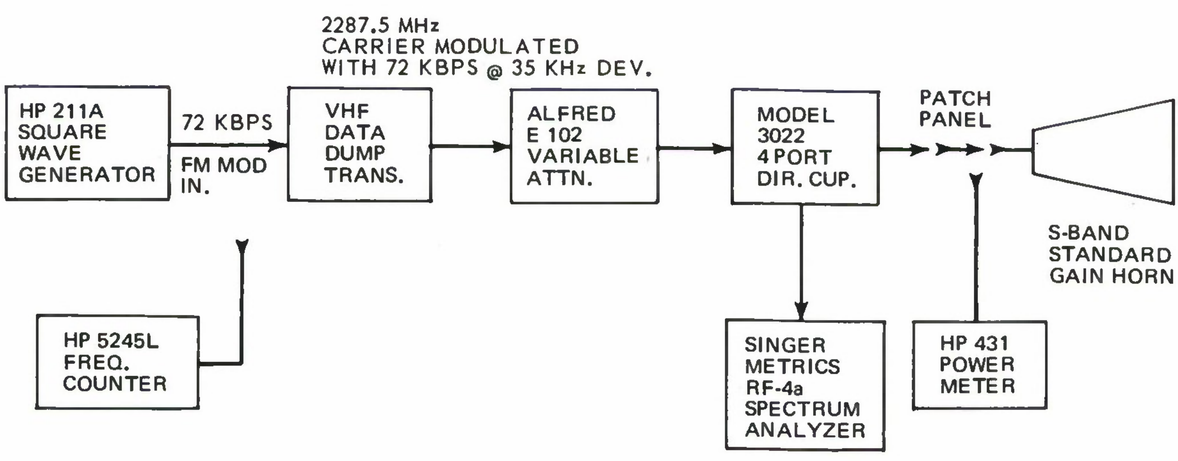


FIGURE 16. TULSA GROUND STATION UHF PCM/FM DATA LINK

f. VHF PCM/FM/FM Data Link Test

The signal requirements for PCM/FM/FM consisted of a 20-Hz square wave from the HP function generator used to pulse modulate 14 subcarriers in the DEI data insertion converter. The 14 subcarriers were fed to a summing amplifier (contained within the DEI data insertion unit). The PCM FM output of the summing amplifier was fed to the frequency modulator of the Bendix VHF/UHF signal generator to produce the final PCM FM/FM output (see Figure 17).

g. In addition to setting the deviation requirements by the carrier suppression method, the spectrum analyzer screen scale was calibrated with 50-KHz markers so that the specified deviation requirements could be checked.

3.1.5.3 A/RIA PMEE Calibrations

3.1.5.3.1 AGC Calibrations

A VHF and UHF pre-calibration was made immediately prior to each mission and a post-calibration was made immediately after each mission. On Flights 18 through 27, an AGC calibration was made between each data run in order to obtain a higher degree of accuracy. The A/RIA PMEE configurations used to make all AGC calibrations are shown in Figures 18 and 19.

Figure 18 is a simplified block diagram of the UHF PMEE calibration system. The signal from the Bendix VHF/UHF signal generator was fed through a variable attenuator to power dividers that distributed the VHF/UHF signal generator output signal to the sum channel directional couplers of each UHF tracking/data receiver. The VHF/UHF signal generator output was initially set to -80 dBm at the directional couplers. Attenuation was then added in 5-dB steps to -100 dBm on VHF and to -100 dBm on UHF. The signals were attenuated in 2-dB steps until receiver break lock. The AGC outputs of both UHF tracking/data receivers were fed to the oscillograph chart recorder and the data multiplexer. The multiplexed AGC output from the data multiplexer was fed to the wideband tape recorder. All AGC calibrations were recorded on both the oscillograph chart recorder and the wideband tape recorder.

Figure 19 is a simplified block diagram of the VHF PMEE calibration system. The VHF tracking and telemetry receiver AGC calibrations were made in the same manner as described above for the UHF receivers. The VHF telemetry and tracking receiver AGC calibrations were all recorded on the wideband tape recorder and the oscillograph chart recorder. The recorded AGC levels were reduced by the data reduction group, compared with the calculated levels, and used for correlating with recorded telemetry data.

3.1.5.3.2 Azimuth and Elevation Tracking Error Calibrations

Ground calibration of VHF and UHF azimuth and elevation error signals was performed twice during the Flight Test Program. Figure 20 is a simplified block diagram

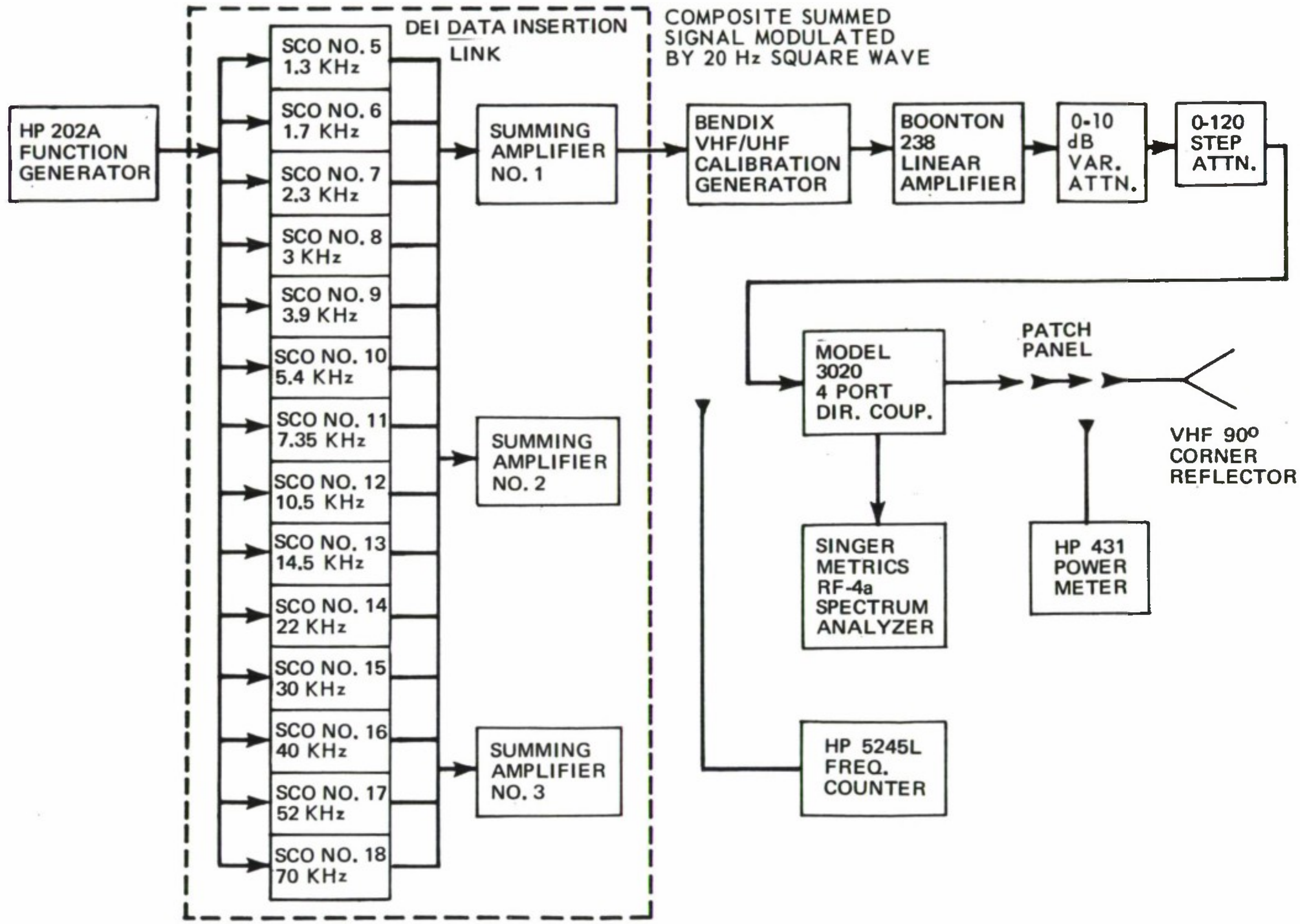


FIGURE 17. TULSA GROUND STATION VHF PCM/FM/FM DATA LINK

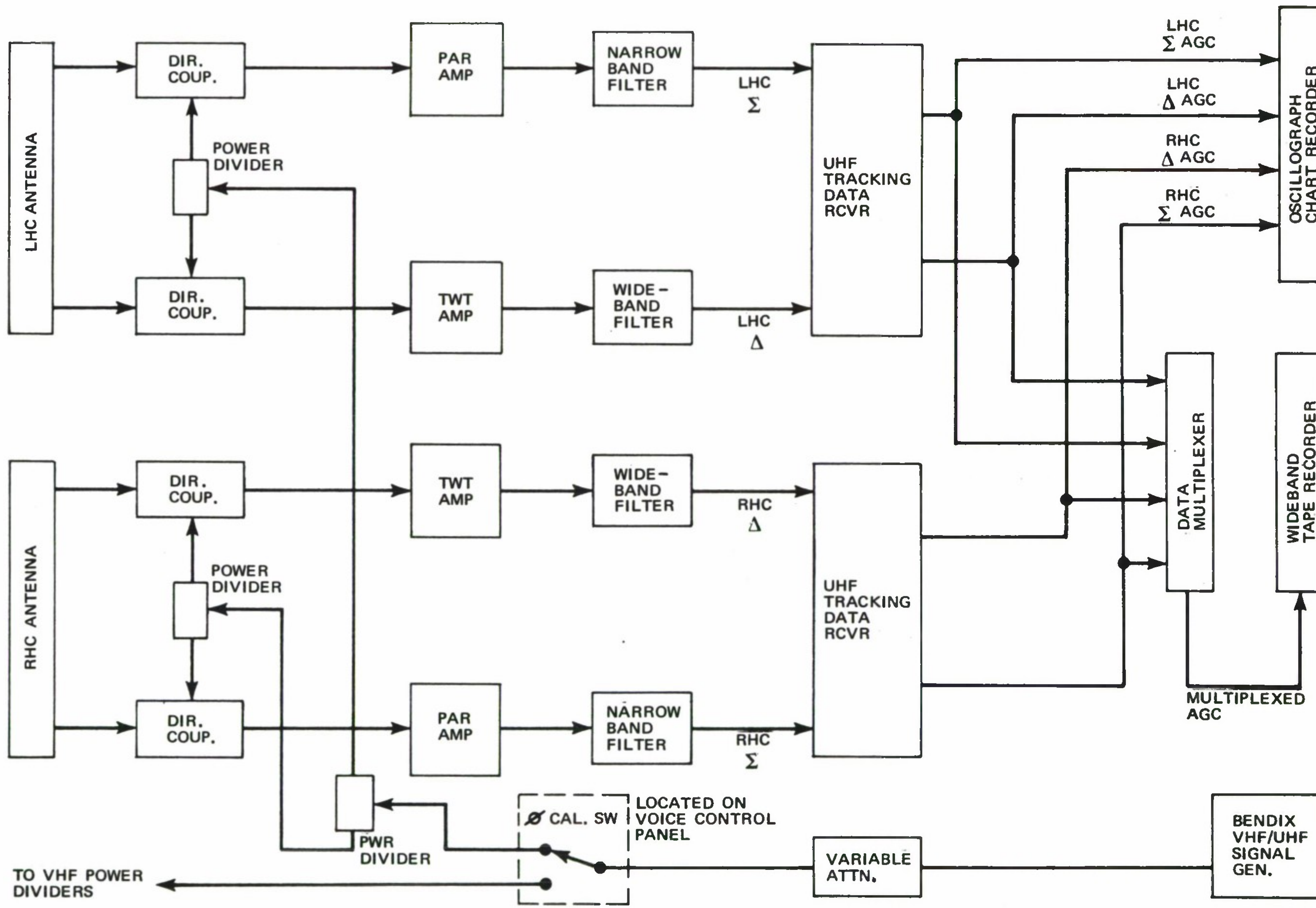


FIGURE 18. UHF CALIBRATION SYSTEM SIMPLIFIED BLOCK DIAGRAM

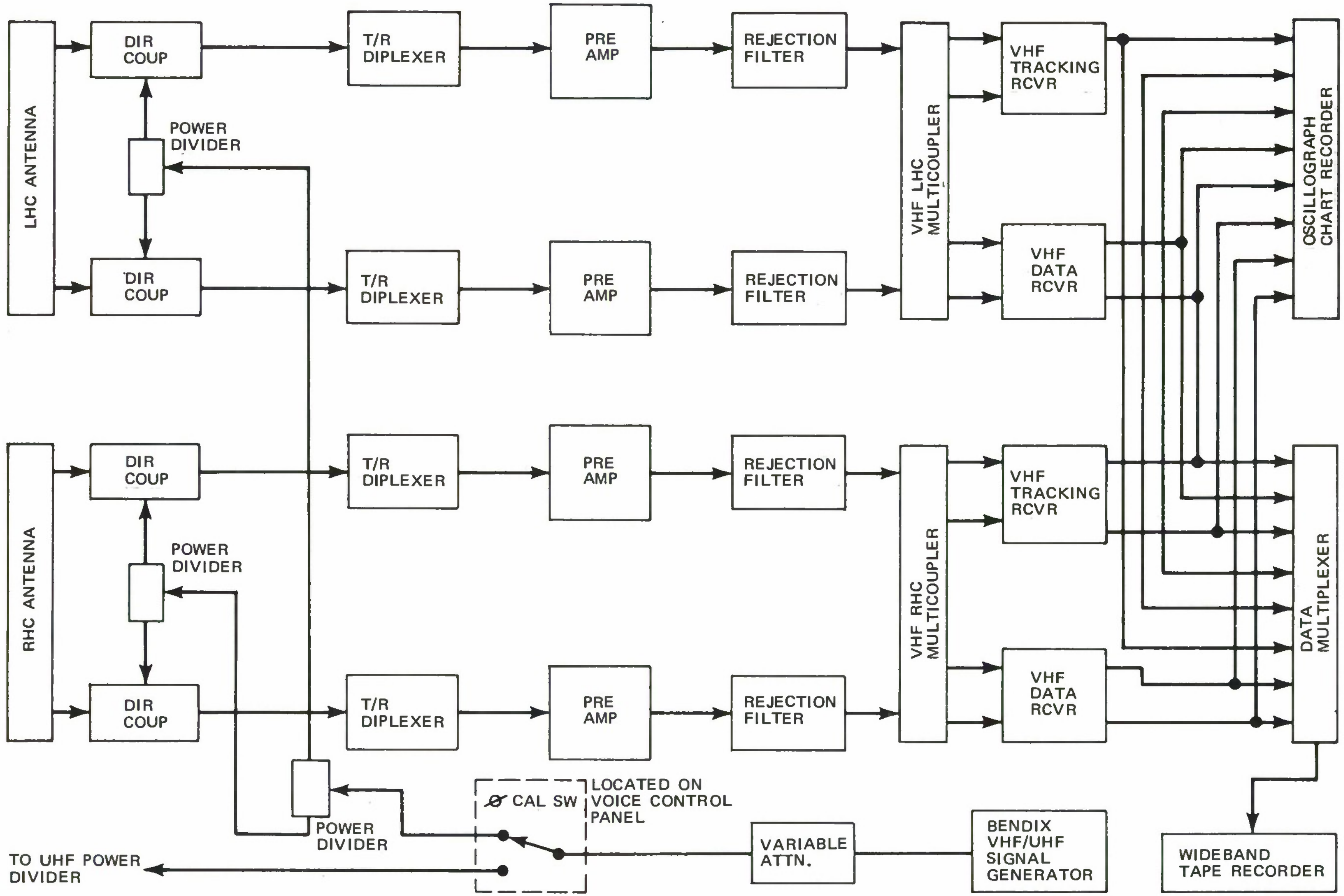


FIGURE 19. VHF CALIBRATION SYSTEM SIMPLIFIED BLOCK DIAGRAM

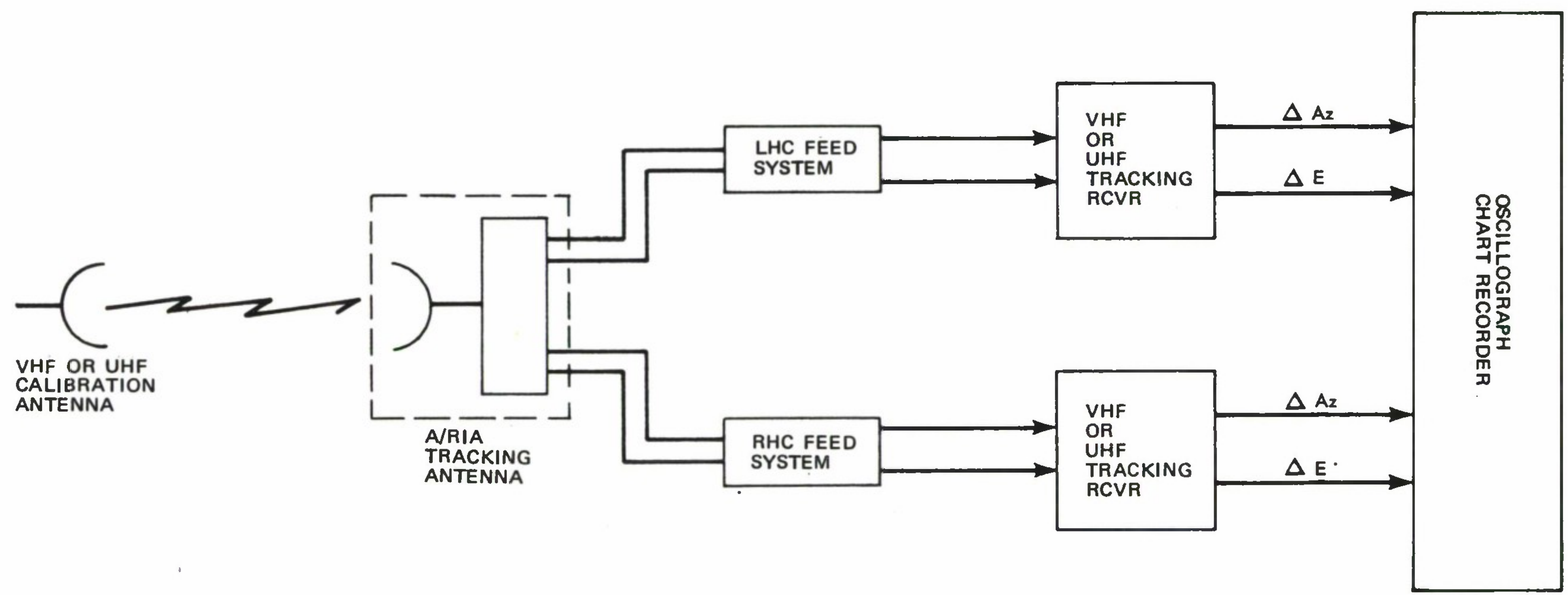


FIGURE 20. AZIMUTH AND ELEVATION ERROR VOLTAGE CALIBRATIONS, PMEE CONFIGURATION SIMPLIFIED BLOCK DIAGRAM

of the VHF and UHF PMEE configuration used for these calibrations. The procedure for UHF calibrations was as follows:

The A/RIA tracking antenna was aligned with the UHF calibration antenna and the receiver phase loops nulled. The azimuth and elevation readings of the A/RIA antenna at this point were recorded. The A/RIA antenna was then offset in azimuth in 1° steps in both the plus and minus direction for 2°. At each 1° step, the signal level was stepped from -80 dBm to -120 dBm; this same procedure was repeated for the elevation calibration.

The VHF system was done in exactly the same manner except the calibration steps were $\pm 2^{\circ}$, 5°, and 10°. The calibrations were all recorded on the oscillograph chart recorder, reduced by the data reduction group, and used to determine tracking stability.

3.1.5.3.3 Signal Level Measurements Aboard A/RIA

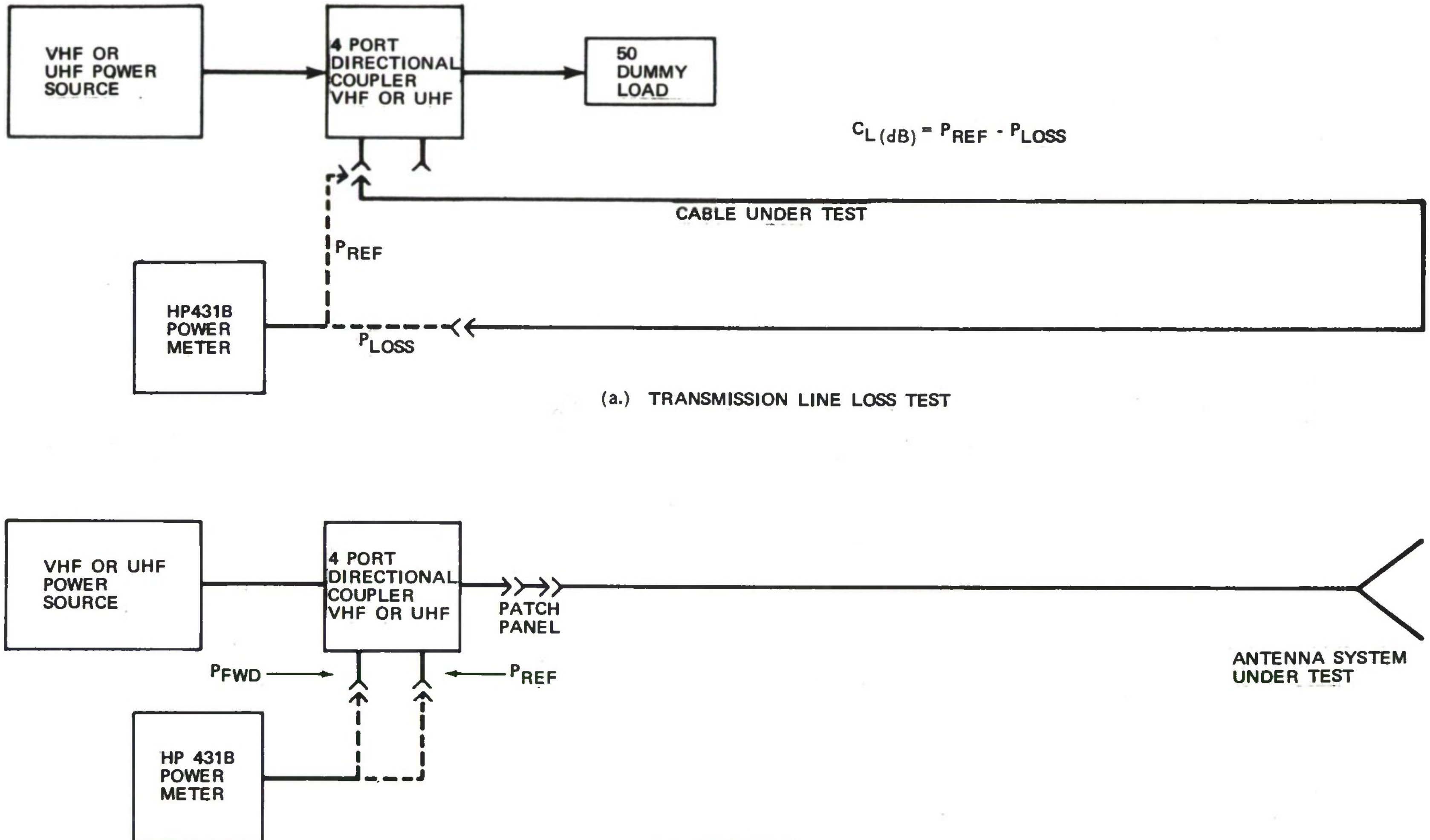
In-flight signal level measurements were made using the telemetry and/or tracking receivers signal level meters. The meters were calibrated in dBm referenced to the directional couplers using the VHF and UHF calibration equipment (Reference Figures 18 and 19). Calibration of the signal level meters allowed the telemetry operator to record accurate signal levels at any point during a data run. It was possible to compare calculated signal levels against actual measurements in the aircraft. The calculated and the measured signal levels normally agreed within ± 2 dB.

Hewlett Packard 400D and Ballantine 320A VTVM's were used aboard the A/RIA to measure signal-plus-noise and noise levels for VHF and UHF voice and telemetry tests (see Sections 3.5 and 3.6). The VTVM readings were compared with voice and data recorded on magnetic tape to provide "quick look" information for flight planning.

3.1.5.3.4 Antenna Mismatch and Cable Loss Measurements (A/RIA Ground Station)

Figure 21(a) shows the configuration used in the ground station for measuring transmission line loss. The VHF or UHF power source was fed through an appropriate four-port directional coupler to a 50-ohm dummy load. The HP 431B power meter was connected to the forward power port of the directional coupler and the power level in dBm was recorded. One end of the cable under test was then connected to the forward power port of the directional coupler and the other end of the cable connected to the HP 431B power meter, and the power level again recorded. The difference in power (dBm) between the first and second power levels was the cable loss.

Figure 21(b) shows the configuration used in the ground station for measuring antenna mismatch loss. Power level measurements were made at the forward power and reflected power ports of the directional coupler.



(a.) TRANSMISSION LINE LOSS TEST

(b.) VSWR TEST

FIGURE 21. TULSA GROUND STATION LINE LOSS AND VSWR TESTS

3.1.5.3.5 NASA C-121 Apollo Simulator

All test parameters associated with the NASA C-121 aircraft, such as modulation requirements, bit rates, and frequency requirements, were set in accordance with Apollo formats. The signal power levels radiated by the C-121 were set as required by direction of the A/RIA Mission Control Coordinator.

3.2 INSTRUMENTATION AND DATA ANALYSIS

3.2.1 General

Instrumentation installed on the A/RIA test aircraft was designed to provide for the collection of data on the performance of the aircraft subsystem (Category I) and PMEE equipment (Category II). This section will deal with that part of the instrumentation which was utilized in the Category II Flight Test Program. A block diagram of the controls and interconnections of the units is shown in Figure 22.

The bulk of the parameters recorded fall into two categories: analog and discrete functions. The analog signals: AGC, tracking error, carrier deviation voltages, etc., were routed to the two CEC oscillographs located in the aft section of the aircraft. The discrete functions: receiver acquisition, receiver break lock, etc., were recorded by the Brush event recorder in the forward section. Antenna and aircraft pointing data were recorded on the photo recorder which photographed antenna azimuth and elevation modules during flight.

Signal conditioning units were designed and used to match the monitored signals to the instruments used for recording.

Each recorder had a coded GMT input as well as a correlation signal channel. This provided accurate timing for the data recorded. The time correlation scheme eased the job of locating a particular event during a flight.

3.2.1.1 Recording Equipment

Category II data were recorded on the CEC oscillographs, the photo recorder, and the Brush event recorder. Over 150 parameters were continuously monitored by these instruments during PMEE flights. A description of each recording system and its accuracy follows; a block diagram of the interface of the PMEE and test instrumentation is presented in Appendix II.

3.2.1.1.1 Oscillograph Recording System

Two 50-channel oscillographs - CEC Type 50-119P3-50, located in the aft rest area, were used to record all dynamic PMEE parameters where a continuous time-history was required. Analog signals routed to the oscillographs included AGC, frequency deviation, carrier deviation, and azimuth and elevation errors.

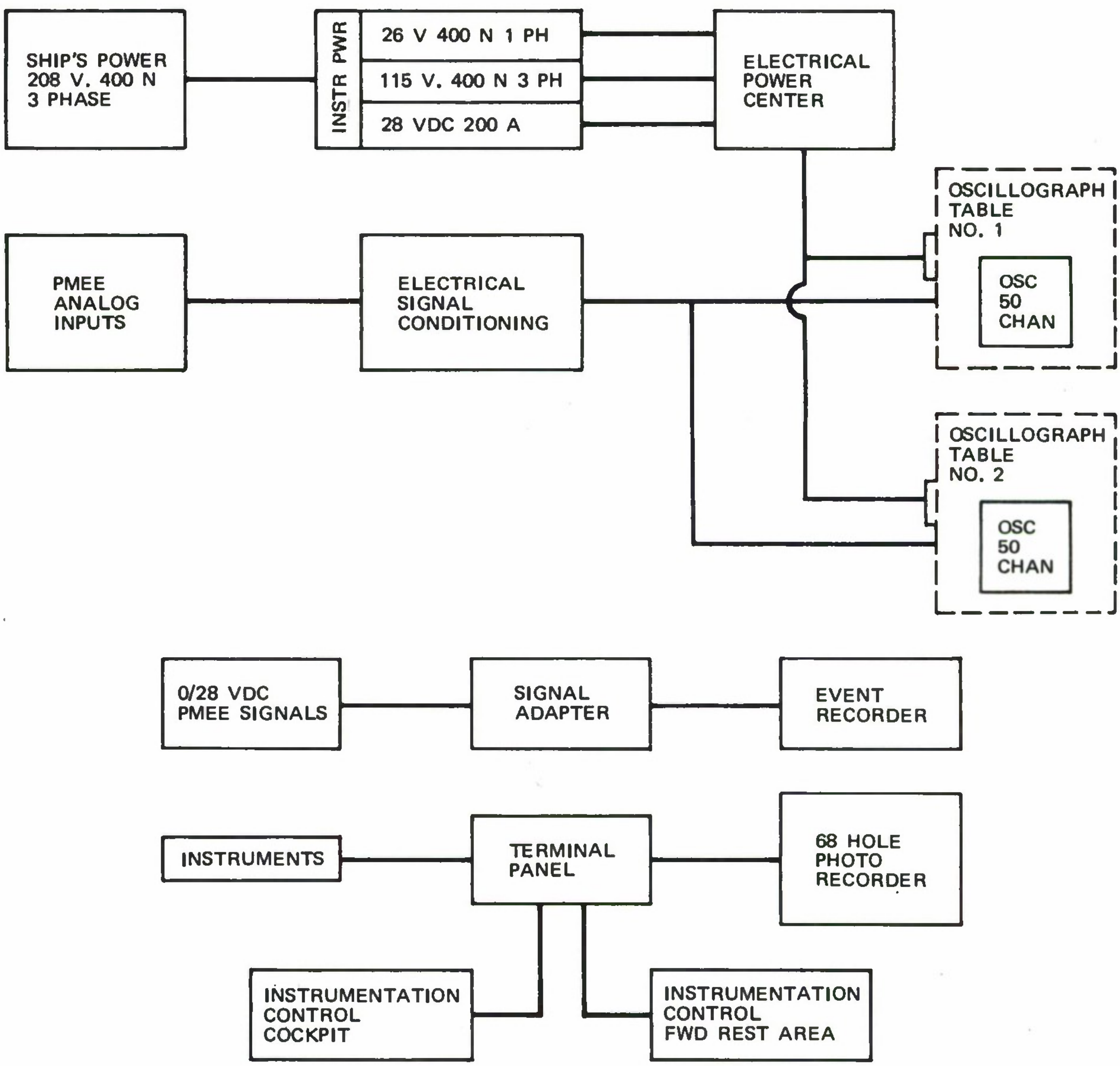


FIGURE 22. A/RIA 372 INSTRUMENTATION BLOCK DIAGRAM

The paper speed of the recorder was set to 2.5 ips to accurately record the deflection and frequency of these parameters. The paper rolls were 475 feet long and 12 inches wide. Timing lines were recorded at -.1-second intervals throughout the flight. The oscillograph paper used was light sensitive, i.e., each trace produced a light beam reflected from a mirror on the galvanometer. These rolls required processing after each flight. Any expansion or shrinkage of the paper during processing was detected by monitoring of the three stationary reference channels.

An IRIG E time code was selected as the timing input on each oscillograph. IRIG E has a 10-second time frame, making it compatible with the 2.5-ips running speed. At 2.5-ips, the width of the 80-ms timing index was 0.2 inch, resulting in a reading accuracy of better than ±8-ms.

In addition to IRIG E, a one-per-second elapsed time indicator number was fed to the oscillograph and event recorders, providing redundant timing. This signal was generated by an IT-4 timer.

Four different galvanometer types were used in the oscillographs, including CEC 7-339, 7-342, 7-349, and 7-351. In selecting the one to be used for a particular measurement, the considerations were input signal level, PMEE output impedance, and frequency response. The galvanometer characteristics (sensitivity and frequency response) affected by these factors are interdependent, requiring the selection of galvanometers to best provide the data required for each type of parameter.

The characteristics for the galvanometers used during Category II testing are shown in Table III.

TABLE III

Galvanometer Characteristics

Model Number	Natural Frequency Response (Hz)	Damped Flat Frequency Response (Hz)	Galvanometer Internal Resistance (Ohms)	Sensitivity Micro (Amps/In)
7-339	50	0-30	30	4.61
7-342	225	0-135	86	10.70
7-349	10	0-6	130	1.62
7-351	20	0-12	33	2.66

Table I in Appendix II lists each PMEE parameter recorded on the oscillographs and outlines the characteristics of the galvanometer circuit used.

3.2.1.1.2 Oscillograph Signal Conditioning Units

Four signal conditioning units (two per oscillograph) were mounted on the oscillograph tables (see Appendix II for photograph). Each unit contained 24 separate channels; each channel consisted of a resistive network with damping, sensitivity, and calibration resistances. These resistors were ±1 percent resistance tolerance, with a temperature stability of 100 PPM/^{O}C. Figure 23 shows the electrical schematic of one channel.

Every signal conditioning unit contained calibration circuits to verify the operation of the galvanometer and signal conditioning circuits. The calibration circuit was used for preflight and post-flight calibrations to insure that the galvanometer sensitivity and zero reading had not changed during the mission. A meter is provided in each unit to monitor the 20-volt mercury cell power source, and to detect any variation in calibration voltage.

All PMEE inputs were fed into their respective units through a signal connector. When the calibration circuits were energized, the connectors were removed to prevent any feedback of the calibration signal into the PMEE equipment.

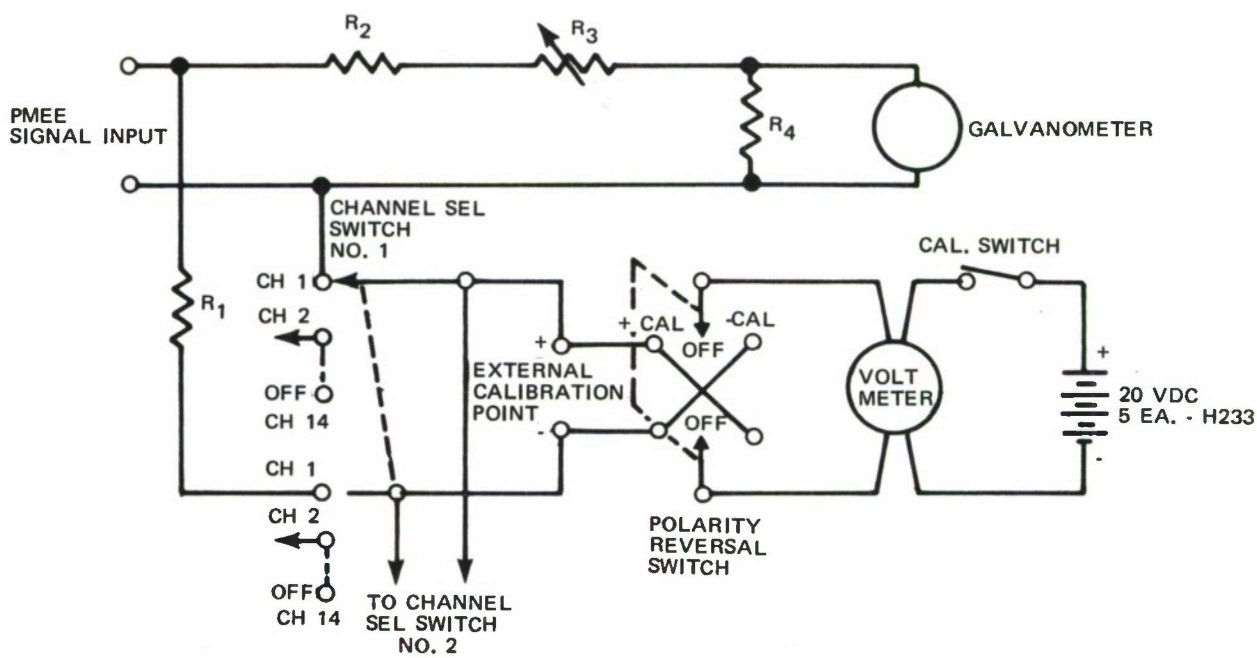


FIGURE 23. OSCILLOGRAPH SIGNAL CONDITIONING UNITS

Oscillograph System Accuracies

There are several areas where direct current error is produced in the galvanometer recording system. Constant errors are independent of the galvanometer full-scale deflection (FSD), and include width of trace, zero shift, paper shrinkage, paper expansion and data reduction readability. Errors influenced by FSD include galvanometer nonlinearity, trace dispersion, and trace deterioration.

Constant errors are minimized by the use of extended deflection. Errors resulting from an extended deflection can be overcome by employing calibration points in the nonlinear range and by proper positioning of the mechanical zero. A sample calculation of these errors is outlined below:

Parameter: Telemetry Receiver 4A AGC

Galvanometer Type: 7-349

Signal Conditioning Unit Circuit Values (ohms):
R1 = 3.9 meg, R2 = 100K, R3 = 200K, R4 = 350K

Signal Input Voltage = 2.5 volts

Deflection at 2.5 volts = 6 inches

PMEE load = 200K $\pm$ 100K

(Five calibration points taken in the operating range to correct for any nonlinearity.)

Non-extended Condition: 2-inch deflection

a. Trace width and data reduction readability error = 0.05 inch

b. Paper shrinkage and expansion error (using three static reference traces) = 0.05 inch

c. Zero shift error (using preflight and post-flight checks) = 0.02 inch

Total error = $\sqrt{(a)^2 + (b)^2 + (c)^2} = 0.074$ inch

Percent of full scale = $\frac{0.074}{2.00}$ = <u>3.7 percent constant error</u>

Extended condition: 6-inch deflection

A 6-inch deflection has the same constant errors, therefore:

Percent of full scale = $\frac{0.074}{6.00}$ = <u>1.25 percent constant error</u>

These calculations illustrate the decrease in galvanometer system error when using the increased sensitivity available with the oscillograph.

The predominant dc error of the oscillograph system is galvanometer non-repeatability with temperature change. This was controlled by having the galvanometer block temperature controlled, and by mounting the oscillographs in an area where the ambient temperature was stable.

Compensation for non-repeatability is difficult because each galvanometer has its own characteristics and monitoring of galvo temperature was not provided. The oscillograph system accuracy given by the manufacturer is ± 5 percent; a large portion of this stated inaccuracy is due to galvanometer non-repeatability.

The recording of dynamic parameters requires choosing a galvanometer capable of the required frequency response. Each model has a known undamped natural frequency and a known flat frequency response. The flat frequency response is 60 percent of the undamped natural frequency and is the upper limiting frequency to which the galvanometer sensitivity remains constant to within ± 5 percent. Recording of tracking and telemetry receiver AGC required a high sensitivity and high impedance galvanometer. The Type 339 galvo had a flat frequency response to 30 Hz, while the Type 349 galvo had a 6-Hz flat frequency response. The signal environment encountered during the Gemini and the missile flight included a multipath frequency higher than 30 Hz. A galvo frequency response curve was used to correct the recording. The correction curves are shown in Figures 24 and 25.

3.2.1.1.3 Event Recorder

The event recorder (Type RE 3610-54) recorded discrete ON-OFF functions. It has a 100-channel capacity and was used for recording such parameters as data receiver acquisition, rate memory activation, VHF optimum selection, etc. Paper speed was 25 mm/second to allow for accurate readout of the IRIG C time code routed to Channel 99.

The 28-volt signals for these descrete function indications were routed to a signal conditioner before application to the recorder. The signal conditioner contains both transistors and relays. The relays were of the Reed type with 2.5-ms maximum operation time while the recorder has up to 2-ms accuracy. Figure 26 presents two typical circuits.

A photograph of the recorder and adapter is shown in Appendix II, which also lists the parameters monitored.

3.2.1.1.4 Photo Recorder

A 68-position instrument located in the forward rest area was adapted and scheduled to record data by camera. Antenna pointing and aircraft heading parameters were the primary PMEE data. The camera was operated by pulses from an IT-4 timer with

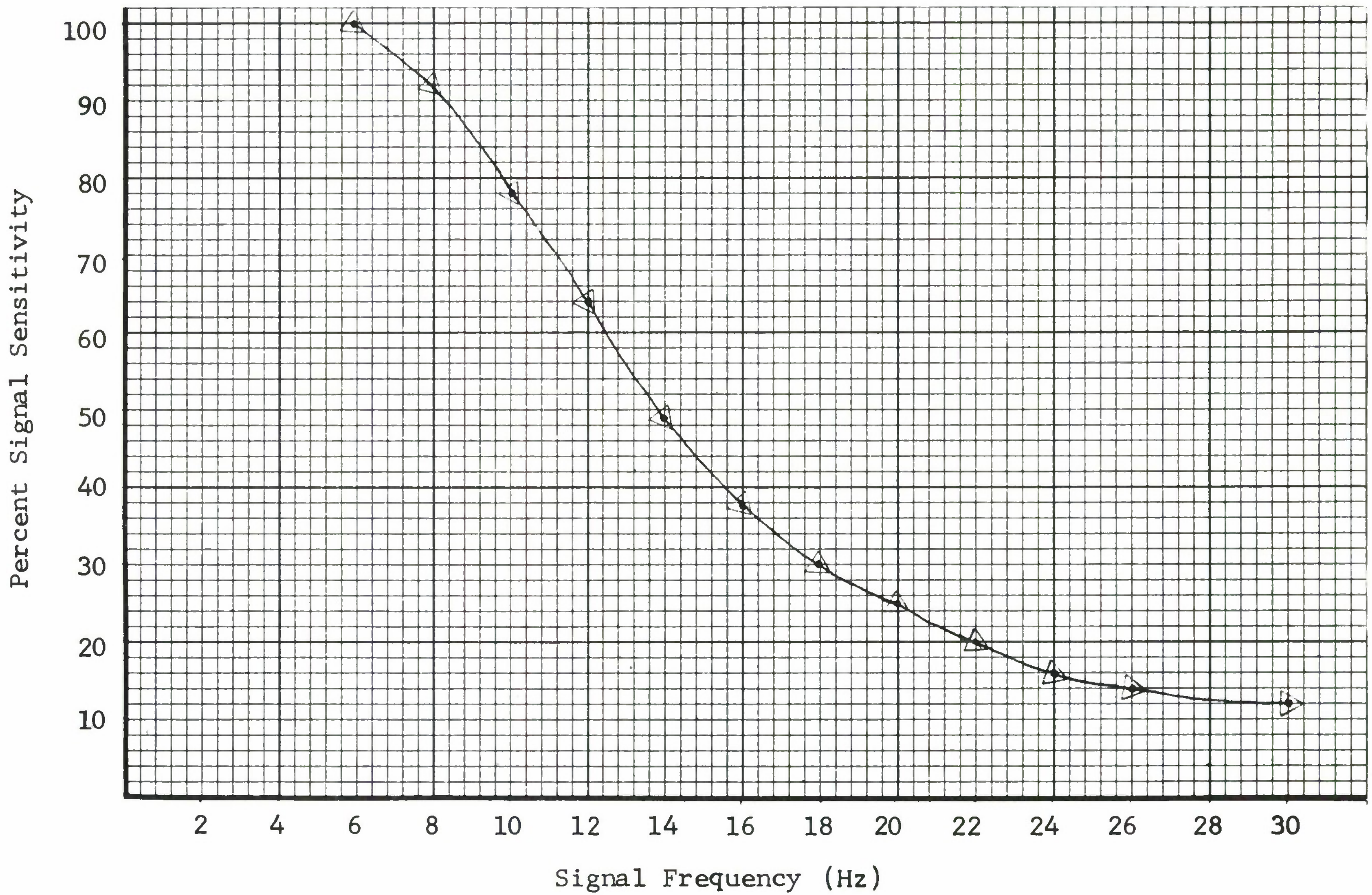


FIGURE 24. MULTIPATH AMPLITUDE CORRECTION CURVE, GALVO TYPE 7-349

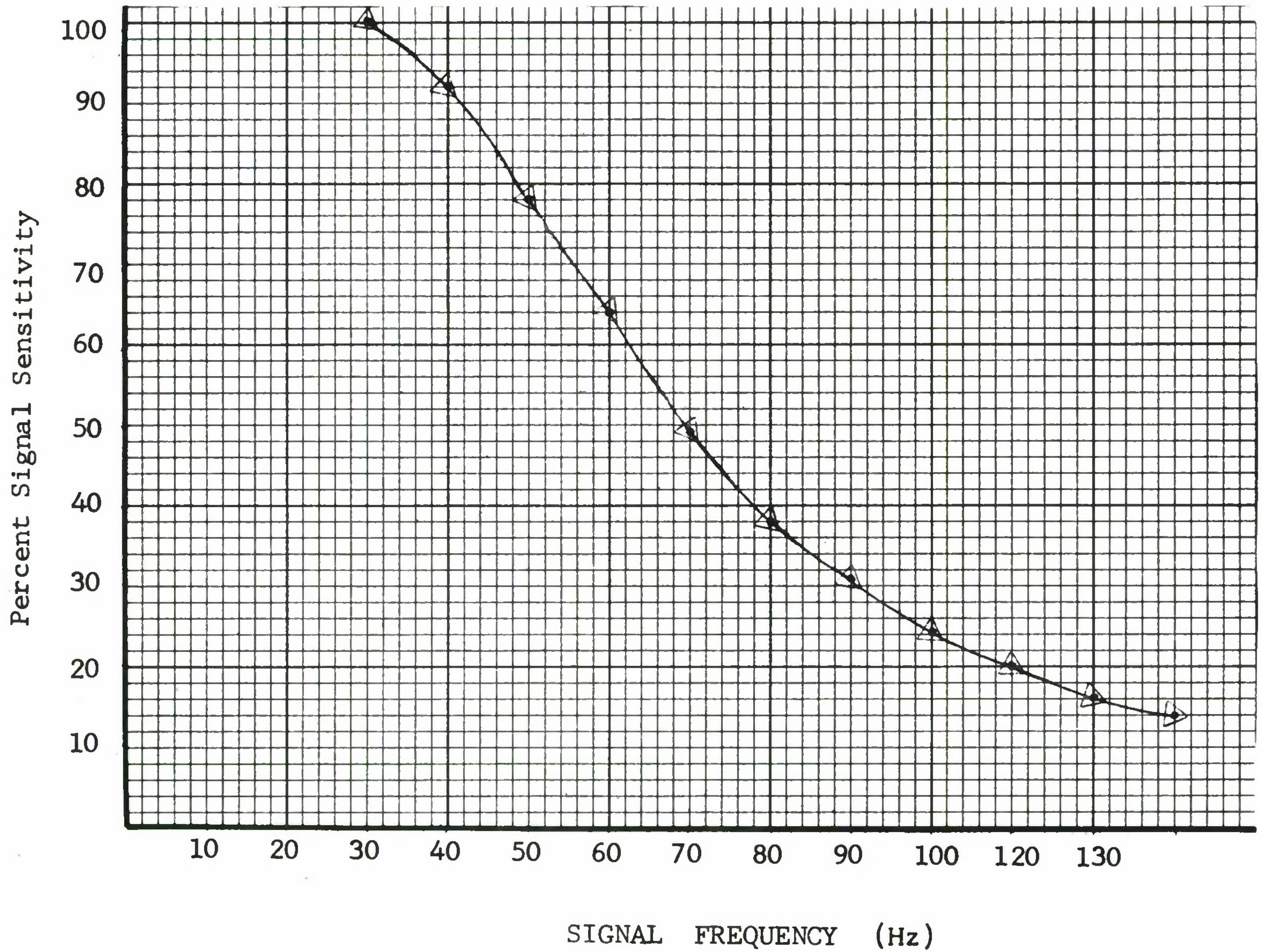


FIGURE 25. MULTIPATH AMPLITUDE CORRECTION CURVE, GALVO TYPE 7-339

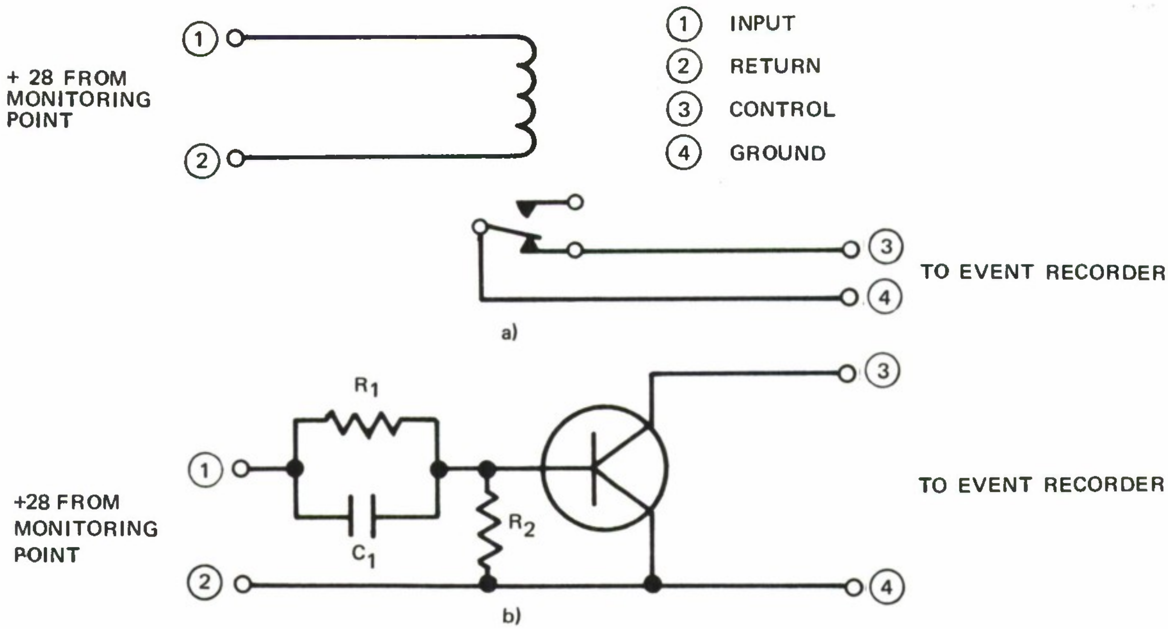


FIGURE 26. TYPICAL EVENT RECORDER SWITCHING CIRCUITS

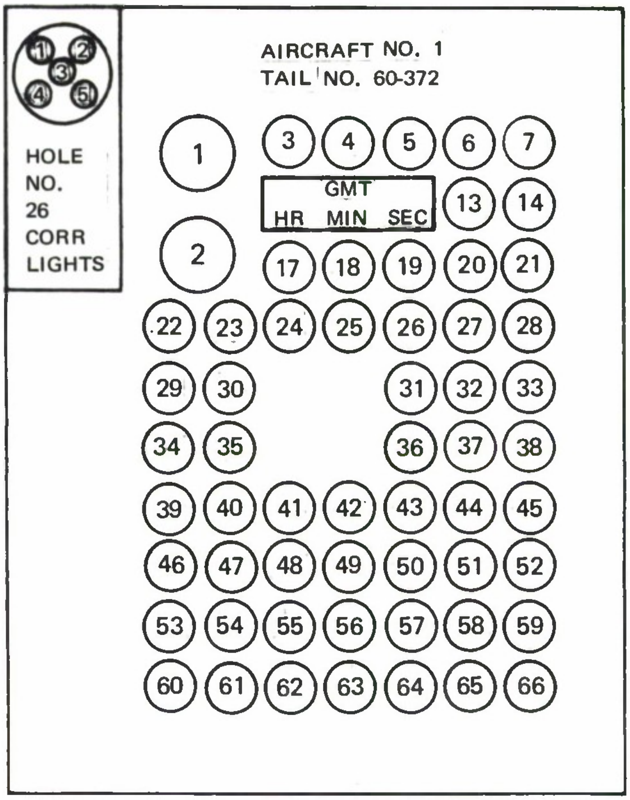
various pulse rates available at a control panel. A photograph of the recorder is shown in Appendix II, while each instrument used and its accuracies are presented in Figure 27.

3.2.2 Data Reduction and Analysis Management

Data reduction and analysis during Category II were predominantly associated with tests of the PMEE. The relationship of the data reduction and analysis functions to the test planning and test operations is shown in Figure 28, which indicated how the requirements of the basic system specification are fulfilled. The detailed steps involved in data reduction and analysis and the manner in which the data are used are illustrated in Figure 29. This second figure shows the additional processes involved in the event that a test result does not meet a test goal or specification requirement.

The data reduction methods are conventional for the type of instrumentation used. The analytical techniques are tailored to the nature of the test and data obtained. For this reason, data reduction and analysis procedures are discussed in each of the Sections 3.4 through 3.12, inclusive, which present test results.

In each instance, test results are referenced to baseline data. These baselines are derived either from a theoretical subsystem analysis or the results of ground testing, performed under controlled conditions, or both. As the flight tests progressed, the level of confidence in baseline criteria was increased by comparison with results from the individual PMEE functions flight tests. If the flight test results agreed with the expected performance goal, this was then considered a figure-of-merit and the



POSITION	MEASUREMENT	INSTRUMENT	ACCURACY	READABILITY
1	AIRCRAFT MAGNETIC HEADING	Az -IND	±2 DEG	±0.5 DEG
1	ANTENNA AZIMUTH	Az -IND	±2 DEG	±0.5 DEG
2	ANTENNA ELEVATION	ELE-IND	±2 DEG	±0.5 DEG
11	GMT	TIME DISPLAY	STANDARD	1 SEC. DIGITAL
24	BEARING HEADING	BDHI	±3 DEG	±2 DEG
24	DISTANCE	BDHI	±0.1 MILE + 2% OF READING	4 DIGITS
26-1	CORRELATION	LIGHT	N.A.	N.A.
27	REAL TIME	CLOCK		1 SEC
28	1 SECOND COUNT	COUNTER	N.A.	N.A.
64	A PHASE BUS TIE VOLTAGE	VOLTMETER	1% F.S.	1.5% F.S.
65	B PHASE BUS TIE VOLTAGE	VOLTMETER	1% F.S.	1.5% F.S.
66	C PHASE BUS TIE VOLTAGE	VOLTMETER	1% F.S.	1.5% F.S.

NOTES N.A. NOT APPLICABLE
F.S. FULL SCALE

FIGURE 27. PHOTO RECORDER LAYOUT AND SCHEDULE

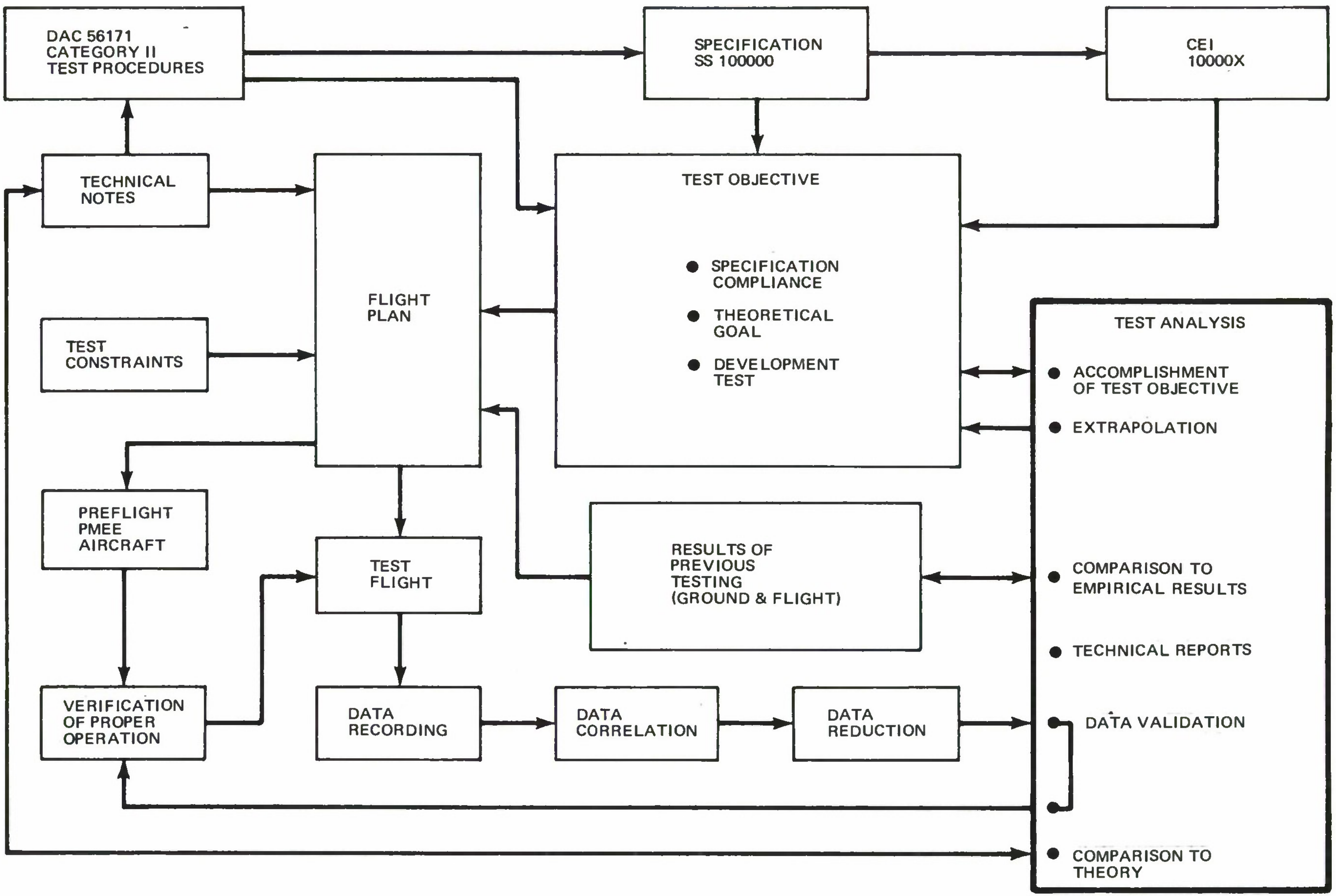


FIGURE 28. TEST ANALYSIS LOOP

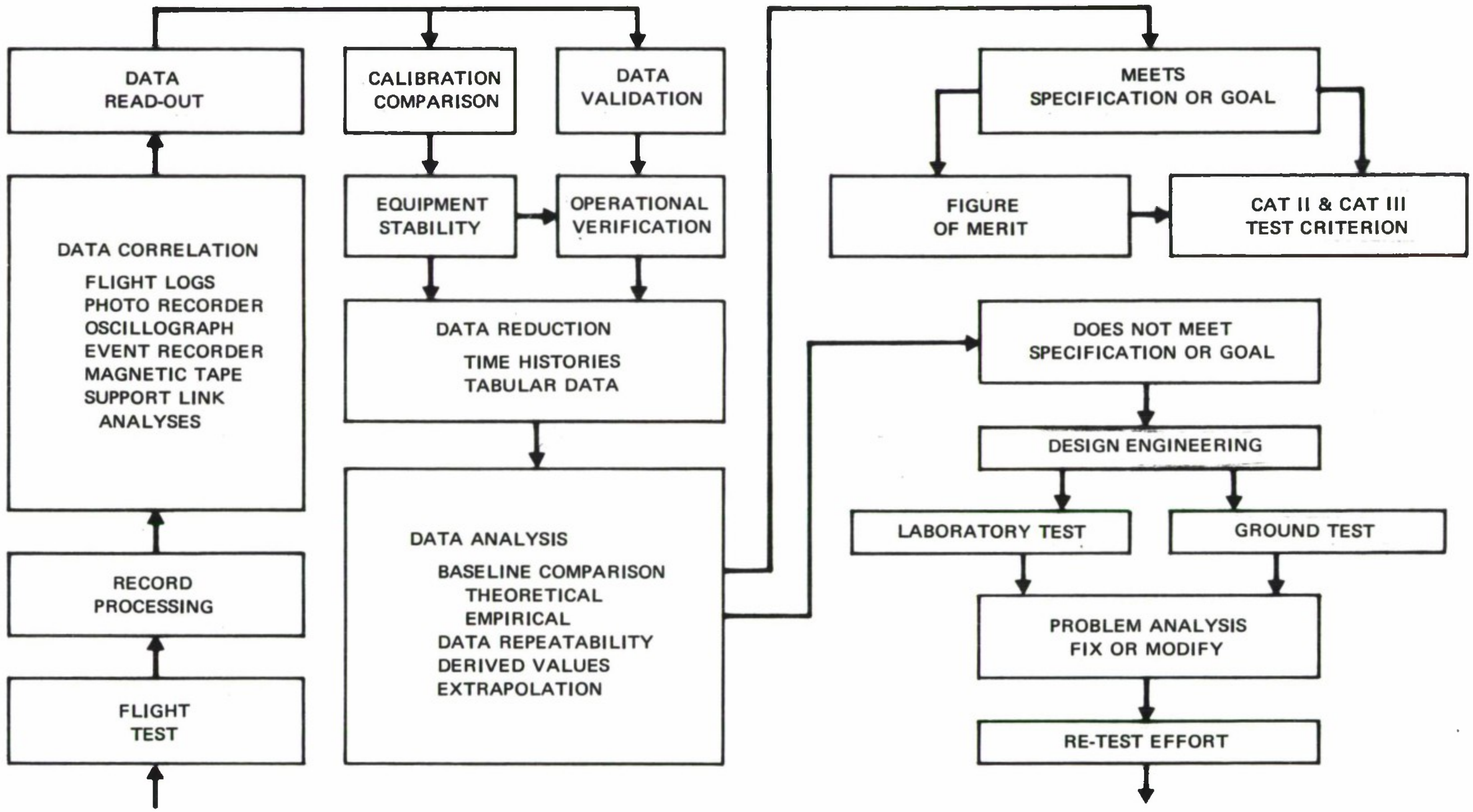


FIGURE 29. DATA FLOW

criteria for subsequent Category II tests. If, on the other hand, there was disagreement between the test results and the baseline, both were analyzed to determine the source of the disagreement. If necessary, retest and analysis were performed until baseline consistency was obtained. With the baseline data thereby validated, the criteria for full PMEE subsystem testing were reaffirmed.

The basic principle of ensuring that the test results are representative of a properly operating test specimen was implemented as shown in Figure 28. The PMEE preflight, the in-flight verification and calibration, and the analyzed test results formed a closely monitored loop during the program. When these analyzed results indicated that component operation was not in accordance with expected characteristics, additional laboratory testing was performed under the direction of design personnel. In those instances where a component malfunction or maladjustment, or operator error were found to exist, the data were excluded from the quantitative analysis of subsystem performance. These occurrences were incorporated into the maintainability, reliability, or PSTE results as applicable. Continuing equipment problems are discussed under the title Design/Operational problems found at the end of each major test section.

Evaluation of subsystem performance was made only after adequate quantitative data were obtained and analyzed to support the evaluation. Datum repeatability was very important, and this exacting requirement dictated test repeats where datum scatter had first yielded inconclusive results. The dynamics of the flight test environment were expected to produce some scatter; however, this was minimized by tight control of the instrumentation and signal environment (discussed in Sections 3. 2. 1 and 3. 1. 5).

As mentioned before, the methods of analysis were determined by the test objective and the data obtained. A brief description of the major methods together with an example of each follows.

3. 2. 2. 1 Sampling of Data to Arrive at Figures-of-Merit

Time slices of characteristic data for a specific test were analyzed individually and collectively to establish datum trend and repeatability. Any anomalies were also analyzed to determine the validity of the data. The evaluation of VHF tracking accuracy and stability (Section 3. 4. 1. 5) serves as an example of this technique.

Ten time slices from four different data runs were used to compile the total sample. Points were read at 0. 5-second intervals throughout a 10-second period. The following parameters were reduced to engineering units and incorporated as time histories:

Azimuth and Elevation Tracking Error Signals

Sum Channel AGC (Calibrated Signal Strength)

Antenna Position - Azimuth and Elevation

A statistical approach was made to the numerous datum points, and the test results were presented as a percentage of time that the antenna remained within $\pm 2^{\circ}$ of the actual target pointing angle. Each of the entire data runs was scanned to ensure the true representation of the samples. The anomalies were analyzed and noted.

3.2.2.2 Correlation of Flight Test Results to Baseline Data

A large portion of the specification compliance tests was confirmed with this method. As an example, the method was used to confirm that telemetry-recorded data met the performance goals (Section 3.5).

The magnetic tapes were reduced, and the measured signal-to-noise ratios (SNR) were tabulated. These SNR values were then compared to the expected SNR at each measured signal level. The theoretical values were derived by applying the appropriate formulas, corrected for known equipment characteristics (i.e., empirical receiver and wideband recorder limitations, filter skirts, etc.) to the data modulation scheme. The final results and conclusions were derived from these comparisons.

3.2.2.3 Data Extrapolation

Areas of data extrapolation include all portions of the report where recommendations and conclusions are drawn about A/RIA performance in areas beyond the test environments. The primary application of this method was used in the extrapolation of Category II test results to Apollo (Section 3.12.3). The test data were used in appropriate formulas, and in some instances compared to the theoretical values to predict PMEE performance during an Apollo mission. The more significant values obtained from test data were to:

System Noise Temperature

Telemetry Data and Recording Parameters

Acquisition Threshold

Tracking Performance

3.3 INCENTIVE MILESTONE DEMONSTRATION

3.3.1 Concept of Demonstration

A Milestone Schedule was established for the A/RIA Program to provide incentives for timely fulfillment of contractual obligation. Nine "Milestones of Achievement" are listed as Schedule Incentives on page 10 of the A/RIA Contract, AF19(628)-4888 dated 4 October 1965. The criteria for acceptance were revised in Attachment "A" to the contract dated 23 May 1966. Milestones 1 and 2 were A/RIA subsystem (PMEE) ground tests, and prerequisites to Milestone 3. Milestones 3 and 4 occurred during the Category II test period, and so are presented in detail in this report. Milestone 5 through 9 are tied to aircraft and equipment deliveries.

Milestone 3 demonstrated the availability of one A/RIA system for the first Apollo mission (AS-204) by 7 November 1966. (The Apollo was scheduled for early December.) It was recognized that this would be early in the Category II Test Program and, therefore, the evaluation of the readiness of the aircraft would necessarily be primarily qualitative. The requirement was to show that the UHF/VHF antenna would acquire and track signals, that the recorder would record these signals, and that HF communication could be established with a ground station. One flight had to be performed wherein all the equipment for the above demonstration functioned as an integrated system using the parameters required for the Apollo mission.

Milestone 4 demonstrated that three A/RIA (systems) were ready for the second Apollo mission (AS-205) by 27 December 1966. All three aircraft were required to have the PMEE and all other elements installed and functions performed as described above for Milestone 3.

Other prerequisites for both Milestones 3 and 4 were:

a. The aerodynamic and structural flight tests (being performed on another A/RIA) were to have proceeded far enough so that the only flight restrictions remaining on the aircraft were those which would be permanent restrictions on the A/RIA fleet, except for any resulting from inadequate time to incorporate revisions to resolve any problems identified late in testing.

b. The PMEE was "to be tested in flight against the aircraft systems to prove that no incompatibility exists that would preclude the use of the required equipment necessary for the specified Apollo Mission."

Both Milestones 3 and 4 were accomplished by flights against the Tulsa A/RIA ground station with its very stable signal environment, and flights against the C-121 Apollo Simulator aircraft. Since the C-121 has the unique Apollo spacecraft-type transponder equipment installed, it was the only available source of airborne telemetry data and voice transmissions which could be used to evaluate and develop in-flight procedures for the A/RIA system. It was recognized that there were definite limitations to the performance of the C-121 as an Apollo Simulator. Its slow speed and low altitude (compared to the Apollo) and restriction to vertically polarized signals, all tend to limit the use of the vehicle. However, both voice and telemetry signals comparable to those to be used by the Apollo vehicle can be transmitted. In addition, the C-121 has a Unified S-Band (USB) capability which the Tulsa A/RIA ground station did not acquire until some time later.

3.3.2 Milestone 3

3.3.2.1 Conduct of Demonstration

The No. 1 A/RIA first flew on 19 September 1966. Two flights were made to evaluate the aircraft's airworthiness as required by T.O. 1-1-300 and per Worksheets

1C-135A-WS-6-1-CF. These flights were made prior to the installation of the Prime Mission Electronics Equipment (PMEE).

The airplane first flew with all PMEE installed on 28 October 1966. The Milestone 3 demonstration flight against the C-121 was made on 3 November 1966. Prior to 3 December, two flights were made against the Tulsa A/RIA ground station in preparation for Milestone 3; i.e., checking out UHF/VHF acquisition, tracking, and recording, and the HF communications subsystem. PMEE/aircraft compatibility was also verified.

Operation of the PMEE was demonstrated on Flight No. 6 of A/RIA No. 1 on 3 November 1966, with the NASA C-121 Apollo Simulator aircraft used as the radiating source. The A/RIA flew at 35,000 feet at 375 knots. The C-121 (NASA 421) flew at an altitude of 20,000 feet, at a ground speed of 220 knots.

The official government observer/verifiers were L/Col. L. Politzer, USAF (ESD); Capt. E. Thomas, USAF (ESD); Mr. H. Nobles PAA (ETR); Mr. R. Dudney, PAA (ETR); Messrs. L. Shelton and K. Shaw of NASA were aboard the C-121. The items demonstrated were:

a. VHF acquisition, tracking and data recording.

b. UHF acquisition, tracking and data recording.

c. USB phase lock loop lockup.

d. VHF and USB voice, two-way voice relay of both via HF (wing probe antennas) with the Tulsa A/RIA ground station.

e. Simultaneous use of all PMEE functions with exception of the HF trailing wire antenna.

f. VHF search and acquisition manually (no sector scan) and by manual slew with sector scan.

g. Rate memory in VHF and UHF tracking modes.

3.3.2.2 Results and Conclusions

Per the requirements of Attachment "A" to the Contract, system ground tests (Milestone 2) were completed on 3 November 1966. Sufficient aerodynamic and structural flight tests were completed on A/RIA No. 2 (as reported in Volume II of Report ESD-TR-67-293) to lift all temporary flight restrictions placed on the airplane prior to the Milestone 3 flight.

The PMEE was tested for compatibility in flight against the aircraft and its other subsystems. Electromagnetic compatibility was verified and is completely reported in the Category I Final Test Report, Douglas Aircraft Company report, DAC 56148;

compatibility with the aircraft electrical subsystems (all four generators paralleled to the SYNC BUS) was demonstrated and is reported in Volume IV of DEV 3769 (ESD-TR-67-293), "Category I Subsystems Flight Test Final Report"; compatibility with the aircraft air conditioning (including PMEE cooling) was shown and is also fully reported in Volume IV of DEV 3769.

The flight of the No. 1 A/RIA against the NASA C-121 Apollo Simulator satisfactorily showed that the UHF/VHF antenna could acquire and track signals from the C-121, that these signals could be properly recorded, and that HF communications could be established (both with the Tulsa A/RIA ground station and with Cape Kennedy). In addition, the operation of rate memory was demonstrated, as well as VHF signal reacquisition after break lock. Satisfactory TTY communications were demonstrated, and also two-way voice communications on VHF and USB between the A/RIA and the ground station. Simultaneous use of all PMEE functions with the exception of the HF trailing wire antenna was satisfactorily shown.

3.3.2.3 Acceptance

Compliance with the requirements of incentive Milestone 3 demonstration was authenticated on 3 November by Lloyd C. Shelton for NASA, Stanley R. Clark for USAF ETR, and Lt. Col. Laurence M. Politzer for the USAF ESD A/RIA Project Office.

3.3.3 Milestone 4

3.3.3.1 Conduct of Demonstration

This Milestone required the demonstration that three A/RIA's were available and ready to support an Apollo Mission. Aircraft Nos. 1, 2, and 3 were the airplanes chosen. The No. 1 airplane, in passing Milestone 3, demonstrated its qualifications for Milestone 4. The demonstration on aircraft Nos. 2 and 3 consisted of three phases: Phase 1 was completion of T. O. 1-1-300 Airworthiness Checks per Check Flight Worksheets 1C-135A-WS-6-1-CF; Phase 2 was a flight of the A/RIA against the Tulsa ground station; Phase 3 was a flyby with a NASA C-121 Apollo Simulator aircraft while the A/RIA was parked on the ground.

Phase 1, Airplane Airworthiness Checks, were completed on A/RIA No. 3 on 25 November 1966 and on A/RIA No. 2 on 20 December 1966. (Note: On No. 2 this consisted merely of completion of the navigator's and flight mechanic's worksheets since No. 2 was the aero-structural demonstration airplane prior to this time.)

Phase 2 flights were completed on A/RIA No. 3 on 8 December 1966 and on A/RIA No. 2 on 20 December 1966. The flights were made at an altitude of 35, 700 feet and at 390 KTAS. All data runs were made using the typical Category II test racetrack pattern. Equipment operation demonstrated on the runs was as follows:

a. Acquired, tracked, and recorded VHF (RHC and OPT) at 51.2 KBPS (MS, AA).

b. Established two-way HF and VHF voice communications.

c. Performed teletype (TTY) communications (transmit and receive) with a ground-based A/RIA (at Tulsa).

d. Demonstrated UHF rate memory.

e. Acquired, tracked, and recorded USB and UHF (RHC, OPT, LHC) (SS, AA) at 51.2 KBPS.

f. Established two-way VHF voice link with Tulsa A/RIA ground station.

Phase 3, the C-121 flyby, was conducted with No. 3 A/RIA on 9 December 1966 as follows:

a. The A/RIA aircraft was parked on the ramp at Douglas/Tulsa with a heading of approximately 0° True.

b. The NASA C-121 Apollo Simulator flew at 15,700 feet. The course flown started at the Bartlesville VORTAC, and headed south on the 172° radial. The aircraft proceeded on this radial to a DME range of 35-nm, where the 277° radial of the Tulsa VORTAC was intersected, then inbound until directly over the Tulsa VORTAC station. The 55° radial was then flown outbound to a DME range of 25-nm, where the data run stopped. The reverse course was flown on a second pass. This flight pattern gave the combination of situations normally found in a spacecraft pass. The start of the pass was at low elevation angles with a low azimuth angular rate of change; during the middle of the pass there was a high elevation angle with a high azimuth angular rate of change; and, finally, at the end of the pass there was return to a low elevation angle with a low azimuth angular rate of change. The total azimuth angle covered was approximately 160°.

c. The PMEE was configured as it would be for an Apollo Mission. The configuration is shown on the block diagram of Figure I-1 in Appendix I.

d. The PMEE demonstration was similar to that covered in Phase 2 with the ground station but, in addition, signal reacquisition after intentionally breaking track was demonstrated. In four passes the following functions were demonstrated:

   (1) Manual and sector scan with auto acquisition.

   (2) UHF RHC and VHF OPT tracking modes.

   (3) USB transponder phase lock.

   (4) Reception and recording of VHF, UHF, and USB TLM data.

(5) Two-way voice communications on VHF and USB between the A/RIA and the C-121.

(6) Rate memory operation.

(7) Reacquisition after intentionally breaking track.

(8) HF communications with another HF station (Cape Kennedy).

(9) Transmit and receive TTY messages.

On the No. 2 airplane, the equivalent of a Phase 3 demonstration was accomplished with both the C-121 and the No. 2 A/RIA in the air. This was accomplished during the flight on 20 December 1966.

3.3.3.2 Results and Conclusions

The airplane's flight characteristics were fully defined prior to the Milestone demonstrations with the completion of the Category I Aero-Structural Flight Test Program on 16 November 1966. (Reference Volume II of Report ESD-TR-67-293.) There were no restrictions on the aircraft other than those permanently placed upon it and appearing in the revision to the Flight Handbook.

Availability of A/RIA Aircraft Nos. 2 and 3 was established with the successful checkout of the VHF/UHF antenna signal acquisition and tracking, the ability of the wideband recorders to record the signals, and establishment of HF communications with a ground station at Tulsa, and Cape Kennedy. In addition, it was shown that the PMEE rate memory operation and ability to reacquire after break lock was suitable. Demonstrations included USB transponder phase lock, and two-way voice communications on VHF and USB between the A/RIA and the NASA C-121 Apollo Simulator; further, it was shown that all of the equipment functioned as an integrated system while using the parameters required for support of the Apollo Mission.

3.3.3.3 Acceptance

The Milestone demonstration was completed on A/RIA No. 2 on 20 December 1966 and on A/RIA No. 3 on 9 December 1966. This coupled with the successful Milestone 3 demonstration on A/RIA No. 1 (3 November 1966) completed the requirements. The "Sign Off" was made by R. K. Dudney for USAF ETR, G. E. Connolly, ESD, and Lt. Col. Politzer, the ESD A/RIA Project Manager on 21 December 1966 (Reference TWX 30161 from ESSIK to DCASO, Douglas Tulsa, dated 27 December 1966).

3.4 ACQUISITION AND TRACKING

3.4.1 Acquire and Track at VHF

3.4.1.1 VHF Test Result Summary

The A/RIA successfully demonstrated the ability to acquire and track at VHF. During the test program, acquisition and tracking tests were performed against the A/RIA ground station, the NASA C-121, Gemini XII, and a ballistic missile. Tracking in circular and linear receive polarizations was demonstrated; circular is recommended for all applications. Tracking limits have been established at approximately $\pm 133^{o}$ in azimuth and $^{+105^{o}}_{-34^{o}}$ in elevation. The VHF acquisition threshold for a 300-KHz IF bandwidth is 8.3 X 10^{-15} watts/m^2; the threshold for a 500-KHz IF bandwidth is 1.1 X 10^{-14} watts/m^2. VHF beam tilt has been shown to result in signal attenuation of 1.1, 1.9, 2.5, and 3.9 dB in the 11^{o}, 16^{o}, 20^{o}, and 23^{o} positions, respectively. The VHF circular receive pattern has no discernible ellipticity. VHF tracking stability was found to be $\pm 2.0^{o}$ (over 90 percent of the time), when tracking the C-121 or the ground station, circular and linear polarization, respectively. A discussion of A/RIA performance against the Gemini and the ballistic missile is covered in Sections 3.12.1 and 3.12.2.

3.4.1.2 VHF Tests Performed

Test 1 Acquire and track at VHF using Manual Scan/Manual Acquisition in a favorable signal environment (3.48 X 10^{-13} watts/m^2). Receive system circular polarization. Acquire RHC, Track RHC.

Test 2 Acquire and track at VHF using Manual Scan/Automatic Acquisition in a favorable signal environment (3.48 X 10^{-13} watts/m^2). Receive system circular polarization. Acquire RHC, Track LHC.

Test 3 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a favorable signal environment (3.48 X 10^{-13} watts/m^2). Receive system circular polarization. Acquire RHC, track optimum.

Test 4 Acquire and track at VHF using Manual Scan/Manual Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system circular polarization. Acquire RHC, Track RHC.

Test 5 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system circular polarization. Acquire RHC, Track RHC.

Test 6 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system linear polarization. Acquire vertical, track vertical.

Test 7 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system linear polarization. Acquire horizontal, track horizontal.

Test 8 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system linear polarization. Acquire optimum, track optimum.

Test 9 VHF/UHF OPT Switchover Test.

Test 10 Evaluate VHF and UHF tracking performance near antenna limits.

Test 11 Determine acquisition threshold of a modulated VHF signal, PCM/FM, with a 300-KHz IF bandwidth and a 500-KHz IF bandwidth.

Test 12 Evaluate VHF beam tilt. Evaluate the lower portion of the VHF beam to determine the roll-off of signal caused by up-pointing at horizontal acquisition (T. P. 7.4.1.C.5).

Test 13 Acquire and track the NASA C-121 on VHF.

Test 14 Evaluate tracking characteristics at VHF (linear polarization).

Test 15 Evaluate effect of ellipticity when receiving on VHF circular polarization.

3.4.1.3 Test Environment

The A/RIA acquired and tracked at VHF against the Tulsa ground station, the NASA C-121, the Gemini spacecraft and a ballistic missile during Category II. A discussion of these facilities, and the control of signals transmitted from them, is included in Sections 3.1.4 and 3.1.5, respectively. The A/RIA flew the various patterns outlined in Section 3.1.3. The environment peculiar to each test performed is covered under the Conditions paragraph of the test discussion.

3.4.1.4 Data Collection Techniques

Evaluation of tracking performance was accomplished by reducing and analyzing the instrumentation records taken during the flights. The received signal power was reduced from calibrated AGC recordings. The aircraft and antenna positional data were taken from photo recorder film. The discrete functions, such as auto track, possible target, tracking mode, etc., were reduced from the event recorder and correlated in GMT to the analog stripouts. Az and E error voltages were reduced from oscillograph records and used to evaluate tracking stability.

3.4.1.5 System Configuration

The A/RIA PMEE configuration used during VHF tracking tests is shown in Figure 30. The signals are received at the VHF antenna, amplified by the two difference channel preamplifiers, and fed to the RHC and LHC tracking receivers. The Az and E error signal receiver outputs are routed to the tracking combiner. If the system is in AUTO TRACK, the selected channel (VHF/RHC or VHF/LHC) is fed to the antenna servo, automatically keeping the antenna pointed at the target. If the system is in MANUAL TRACK, the coordinate converter holds the antenna to the magnetic heading set in by the operator.

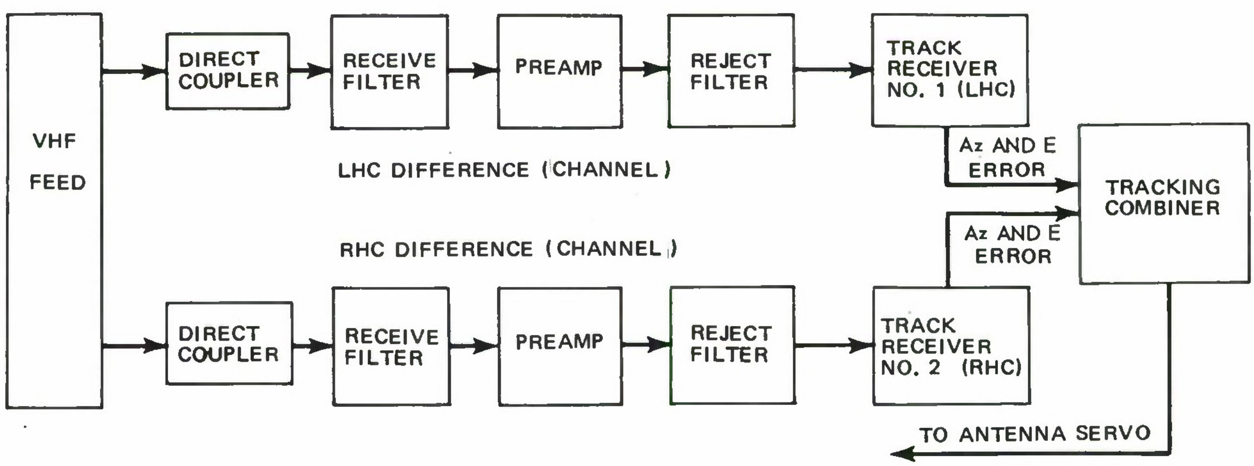


FIGURE 30. PMEE SYSTEM CONFIGURATION FOR VHF TRACKING

3.4.1.6 VHF System Performance —— Tests 1 through 8

The first eight VHF tracking tests were very similar. The difference between each test was the received signal power, the scan/acquisition technique, the tracking mode, or the receive system polarization. For clarity of presentation, these tests are presented together. The tests performed included:

Test 1 Acquire and track at VHF using Manual Scan/Manual Acquisition in a favorable signal environment (3.48 X 10^{-13} watts/m^2). Receive system circular polarization. Acquire RHC, track RHC.

Test 2 Acquire and track at VHF using Manual Scan/Automatic Acquisition in a favorable signal environment (3.48 X 10^{-13} watts/m^2). Receive system circular polarization. Acquire RHC, track LHC.

Test 3 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a favorable signal environment (3.48 X 10^{-13} watts/m^2). Receive system circular polarization. Acquire RHC, track optimum.

Test 4 Acquire and track at VHF using Manual Scan/Manual Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system circular polarization. Acquire RHC, track RHC.

Test 5 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system circular polarization. Acquire RHC, track RHC.

Test 6 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system linear polarization. Acquire vertical, track vertical.

Test 7 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system linear polarization. Acquire horizontal, track horizontal.

Test 8 Acquire and track at VHF using Sector Scan/Automatic Acquisition in a marginal signal environment (1.1 X 10^{-14} watts/m^2). Receive system linear polarization. Acquire optimum, track optimum.

Goal

The first eight VHF acquisition and tracking tests were qualitative evaluations only. These tests were designed and performed to demonstrate that the tracking system would meet the overall design goal, and to detect any gross system problems. All scan and acquisition modes (linear and circular polarizations) were utilized.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station as described in Section 3.1.3. At Point 3 on the pattern, the antenna was pointed to the approximate heading of the signal source, and scan started. When sector scan was used, the scan parameters were:

Az Sector:	$\pm 45^{\circ}$	E Increment:	0°
Az Rate:	15° sec	E Steps:	1

Acquisition was either Automatic or Manual, as indicated in Table IV. Tracking continued to beyond Point 6 on the pattern, where the azimuth limit was reached. Track receivers 1 and 3 had 300-KHz IF bandwidth FM demodulators. The antenna was configured for circular receive in Tests 1 through 5 and linear receive in Tests 6, 7, and 8. The acquisition/track mode was shown in Table IV.

TABLE IV

Test Results - VHF Acquire and Track
Tests 1 through 8

Test No.	Primary Data Derived From: Flight No.	Primary Data Derived From: Data Run	Programmed Power Level (-dBm at Directional Coupler)	Measured Power Level Directional Coupler	Scan/ Acquisition Mode	Source Polar	ACQ Polar	Track Polar	
1	14	1	3.48×10^{-13} w/m^2 -92 dBm	-91 dBm	MS/MA	V	LHC	RHC	Possible target at Point 3. AUTO ACQUIRE initiated manually. Immediate AUTO TRACK. Stable tracking for 11 minute, 43 second, to Point 6.
2	14	2	3.48×10^{-13} w/m^2 -92 dBm	-92 dBm	MS/AA	V	RHC	LHC	AUTO ACQUIRE and AUTO TRACK at Point 3 on RHC. Switch to LHC after 58 seconds. Stable tracking for 11 minutes, 55 seconds to Point 6.
3	14	3	3.48×10^{-13} w/m^2 -92 dBm	-91 dBm	SS/AA	V	RHC	OPT	Start Sector Scan at Point 3. AUTO ACQUIRE and AUTO TRACK on RHC on first sweep. Switch to VHF/OPT after 35 seconds. Stable tracking for 13 minutes, 3 seconds to Point 6.
4	14	4	1.1×10^{-14} w/m^2 -107 dbm	-103 dBm	MS/MA	V	RHC	RHC	Possible Target at Point 3. AUTO ACQUIRE initiated manually. Immediate AUTO TRACK. Stable tracking for 11 minutes, 18 seconds to Point 6.
5	14	6	1.1×10^{-14} w/m^2 -107 dBm	-105 dBm	SS/AA	V	RHC	OPT	Start Sector Scan at Point 3. AUTO ACQUIRE and AUTO TRACK on RHC on first sweep. Switch to VHF/OPT after 58 seconds. Stable tracking for 9 minutes, 15 seconds to Point 6.
6	16	1	1.1×10^{-14} w/m^2 -107 dBm	-106 dBm	SS/AA	V	V	V	Start Sector Scan at Point 3. AUTO ACQUIRE and AUTO TRACK on Vertical on first sweep. Stable tracking for 8 minutes, 52 seconds to Point 6.
7	16	2	1.1×10^{-14} w/m^2 -107 dBm	-107 dBm	SS/AA	H	H	H	Start Sector Scan at Point 3. AUTO ACQUIRE and AUTO TRACK on Horizontal on first sweep. Stable tracking for 7 minutes, 57 seconds to Point 6.
8	16	3	1.1×10^{-14} w/m^2 -107 dBm	-107 dBm	MS/AA	H	OPT	OPT	AUTO ACQUIRE and AUTO TRACK at Point 3 on Horizontal. Stable tracking for 9 minutes, 36 seconds to Point 6.

Test Results

The results of Tests 1 through 8 are shown in Table IV. The measured power levels were taken from oscillographs using the calibration procedure described in Section 3.1.5. The VHF system tracked the target from initial acquisition to Point 6 on the pattern during the eight data runs. Tracking was stable with no loss of track. VHF tracking stability is discussed in more detail in Test 13.

All available scan and acquisition modes were used during the tests. Based upon data evaluation, the optimum operational technique for VHF acquisition is Manual Scan with Automatic Acquisition. The VHF beam width of 40^{o} (3-dB points) makes Sector Scan unnecessary, and manual activation of AUTO ACQUIRE results in an acquisition delay.

At the signal levels used for these tests, there was no discernible difference in tracking performance between the various polarizations (RHC or LHC, vertical or horizontal). From a reliability/operability standpoint, a circular VHF receive system is preferred over a linear one when operating near threshold. A failure of the receiver receiving the compatible polarization, with the receive system linear, would result in a total tracking system failure; the data show that the RHC and LHC channels received the same signal power throughout Flight 14.

3.4.1.7 VHF System Performance —— Test 9

Test for UHF/VHF OPT switchover capability.

Specification/Goal

Evaluate tracking characteristics when tracking in UHF/VHF OPT mode.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station, with the tracking system in UHF/VHF OPT mode. The tracking frequencies were 2287.5 MHz and 237.8 MHz, UHF and VHF, respectively. This test was performed prior to the installation of ACO 10418 in the tracking combiner. This ACO modified the UHF/VHF OPT mode by locking out VHF tracking whenever a UHF receiver has acquired a signal. This modification will be further discussed under the heading of Test Results.

Test Results

This test was performed on Flight 11, Data Run 1. The procedure followed to activate switchover was to either increase or decrease VHF or UHF signal power from the ground station, as indicated in the Events column of Table V (Test 9); the test results are shown in the table.

It is evident from the test results that receiver phasing was not correct during this test. The difference channel null for UHF/RHC was up to 3^{o} Az and 2^{o} E offset from

TABLE V

UHF/VHF OPT Tracking (Test 9)

Test No.		Combiner made at switchover	Signal Strength at switchover (-dBm at Directional Coupler		Antenna Position Correction at switchover		Time Required for Error Channel to Reach 0^{o} Az, 0^{o} E (Stable) (Seconds)	
			VHF (1) (dBm)	UHF (dBm)	Az	E		
	Tracking on VHF	VHF/UHF	-92	-109	--	--	---	
1	Increase UHF power	UHF/RHC	-92	-107	2^{o}	1^{o}	1.3	UHF increased 4dB after switchover
2	Decrease UHF power	VHF/LHC	-90	-109	2^{o}	0^{o}	5.0	UHF decreased 3dB after switchover
3	Decrease VHF power	UHF/RHC	-92 to -102	-115	2^{o}	0^{o}	1.3	UHF increased 3dB at switchover
4	Increase VHF power	VHF/LHC	-102 to -92	-110	3^{o}	1^{o}	6.0	UHF decreased 7dB after switchover
5	Increase UHF power	UHF/RHC	-90	-105	3^{o}	2^{o}	2.0	UHF increased 6dB after switchover

(1) In Tests 3 and 4 the VHF power was changed in a 10dB step; exact VHF power level at switchover is unknown.

(2) Times given include correction after overshoot which occurred on UHF.

the null seen by the VHF/LHC channel. This accounts for the change in received signal seen by the UHF sum channel when the system switched from VHF to UHF tracking, or vice versa.

It appears that the system switched to UHF tracking whenever the UHF signal was within approximately 15 dB of the VHF signal, as measured at the directional couplers. This condition existed even though the differential amplifier in the tracking combiner was set to choose whichever signal was higher, as indicated by absolute AGC volts from the receivers. The combiner saw equal AGC volts on both channels when the UHF channel was down 15 dB because the UHF channel has a higher preamplifier gain than the VHF channel.

Analysis of the VHF Az and E error signals shows that the VHF system took much more time than the UHF system to null out after switchover occurred. Also, no overshoot was indicated on VHF. The UHF channel pulled the antenna to 0° error within 0.3 second, but overshot once and took an additional second to stabilize. The slow servo response on VHF has been isolated to the improper positioning of the L-Band/VHF Servo Gain Compensation switch in the tracking combiner chassis. This switch was in the L-Band position rather than the VHF position. This problem is discussed in detail in Section 3.4.4, Design/Operational Problems.

A modification has been accomplished on the tracking combiner since the end of the Category II Flight Test Program (ACO 10418). This modification resulted in rewiring of the UHF/VHF OPT function to provide a lock-out of VHF tracking whenever either UHF tracking receiver indicates signal acquisition. Signal acquisition initiates AUTOTRACK.

3.4.1.8 VHF System Performance —— Test 10

Evaluate VHF and UHF tracking performance near antenna limits.

Specification/Goal

System will track to $\pm 100^{\circ}$ in azimuth and $^{+100^{\circ}}_{-30^{\circ}}$ in elevation. Determine signal roll-off at the limits.

Conditions

All limits tests were performed in a favorable signal environment. The azimuth limit tests were performed with the A/RIA flying against the ground station, using the flight plan shown in Figure 31. The lower elevation limit tests were performed with the A/RIA flying an inbound radial to the ground station in to 17-nm. The upper elevation limit tests were accomplished by the A/RIA flying a tail-chase to the NASA C-121.

All VHF limits tests were performed with the system in circular polarization, using a 300-KHz IF bandwidth against the ground station and C-121, both vertically polarized. The UHF azimuth and lower limits tests were accomplished against a vertically

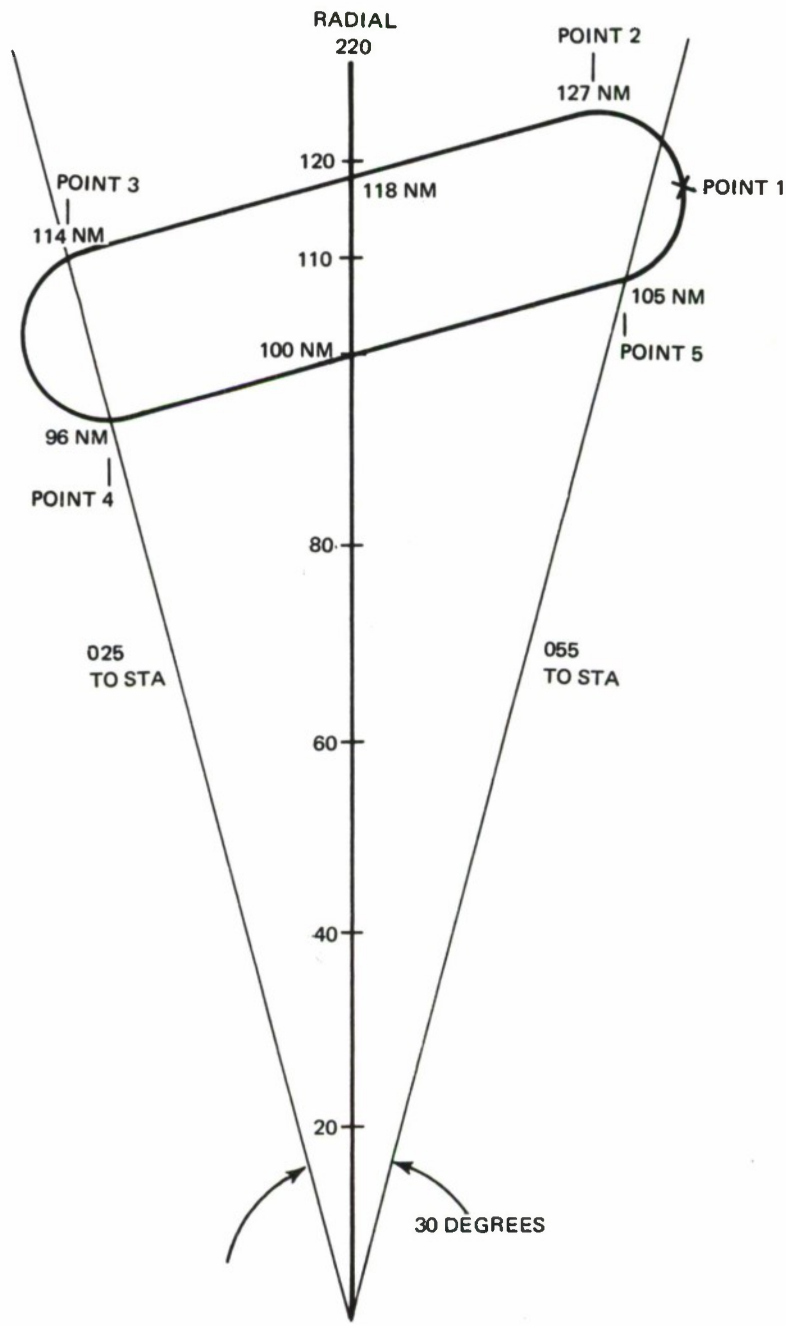


FIGURE 3-1. TULSA GROUND STATION CROSS-TRACK FLIGHT PATTERN

polarized source using a 300-KHz IF bandwidth. The upper limit was run with the receiver configured for Unified S-Band, using a 3.3-MHz IF bandwidth.

Test Results

Plots of the test results are shown in Figures 32 through 37.

VHF Azimuth Limit Test

Figure 32 is a time history of the VHF azimuth limit test, showing the VHF signal strength (sum channel AGC), the azimuth position of the antenna relative to aircraft heading, and the magnetic heading of the antenna. These data were reduced for the period between Points 3 and 5 of the crosstrack flight pattern (see Figure 31). The antenna position during this period ranged from 112° to 133° off of aircraft heading during straight and level flight. The azimuth and elevation limit indicators came on at approximately 133°.

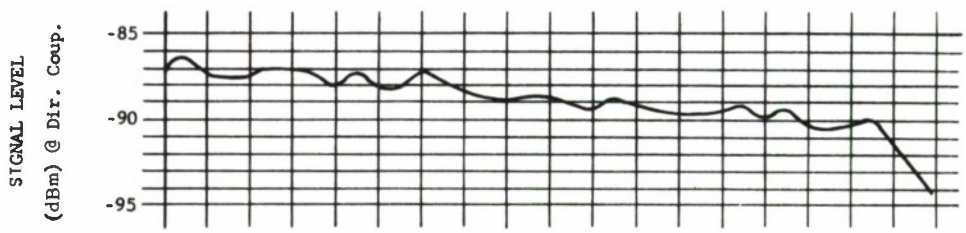
The system was tracking on VHF RHC, and data indicate that the antenna remained within $\pm 3^{\circ}$ of the magnetic bearing to the ground station as it approached the mechanical limits. Antenna elevation variations were less than $\pm 2^{\circ}$ during the run. Short term (less than 10 seconds) signal strength variations were less than ± 1 dB. System tracking was essentially stable and accurate as the aircraft flew up to approximately 133° off of the target heading. This test shows that the system tracked 33° beyond the requirement of $\pm 100^{\circ}$. Figure 33 is an expansion of the last 70 seconds of the run, showing the signal roll-off at the limit.

UHF Azimuth Limit Test

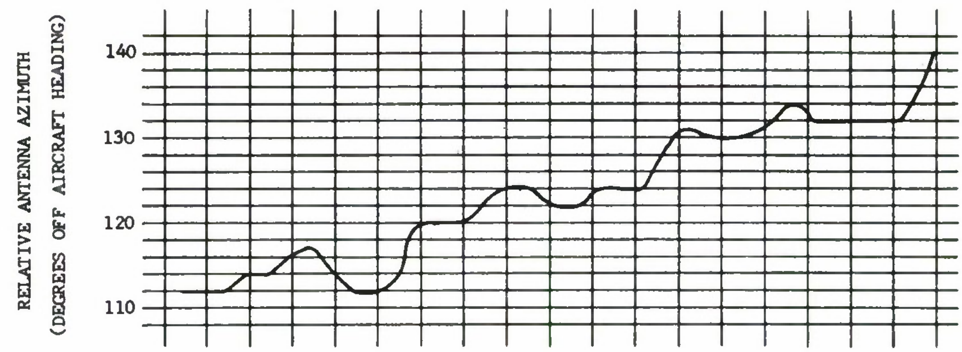
Figure 34 is a time history of the UHF azimuth limit test. The plot shows the UHF signal strength (sum channel AGC), the azimuth position of the antenna relative to aircraft heading and the magnetic heading of the antenna. These data were reduced for the period between Points 3 and 5 of the crosstrack flight pattern (see Figure 31); however, only the first 200 seconds are shown to permit a more accurate presentation. The antenna position during this period ranged from 115° to 127° off of aircraft heading.

The system was tracking on UHF RHC during the limit test, and at azimuth angles beyond 100° right, tracking accuracy was approximately $\pm 1^{\circ}$, with average short term variations of $\pm 0.5^{\circ}$. These accuracies were derived by measuring changes in sum channel AGC and Az and E error signals. System tracking on UHF was essentially stable and accurate as the aircraft flew up to 130° off of the target heading. Figure 33 shows an expansion of the last 80 seconds of the run, showing the signal roll-off at the limit.

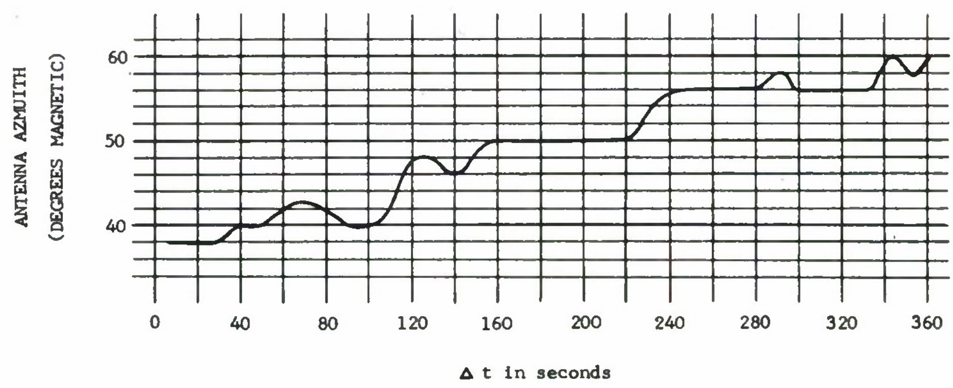
The conclusions derived from the VHF and UHF azimuth limit tests, concerning the absolute number of degrees the system will track off of the aircraft heading, are applicable only to the elevation used herein. The movement of the antenna at different elevations will result in different azimuth limits. The more significant information



a) VHF SUM CHANNEL AGC, RHC, IN -dBm AT THE A/RIA DIRECTIONAL COUPLER



b) NUMBER OF DEGREES (AZIMUTH) THAT THE ANTENNA IS POINTED FROM AIRCRAFT HEADING



c) MAGNETIC BEARING OF THE ANTENNA TO THE GROUND STATION

FIGURE 32. VHF TRACKING AT AZIMUTH LIMITS

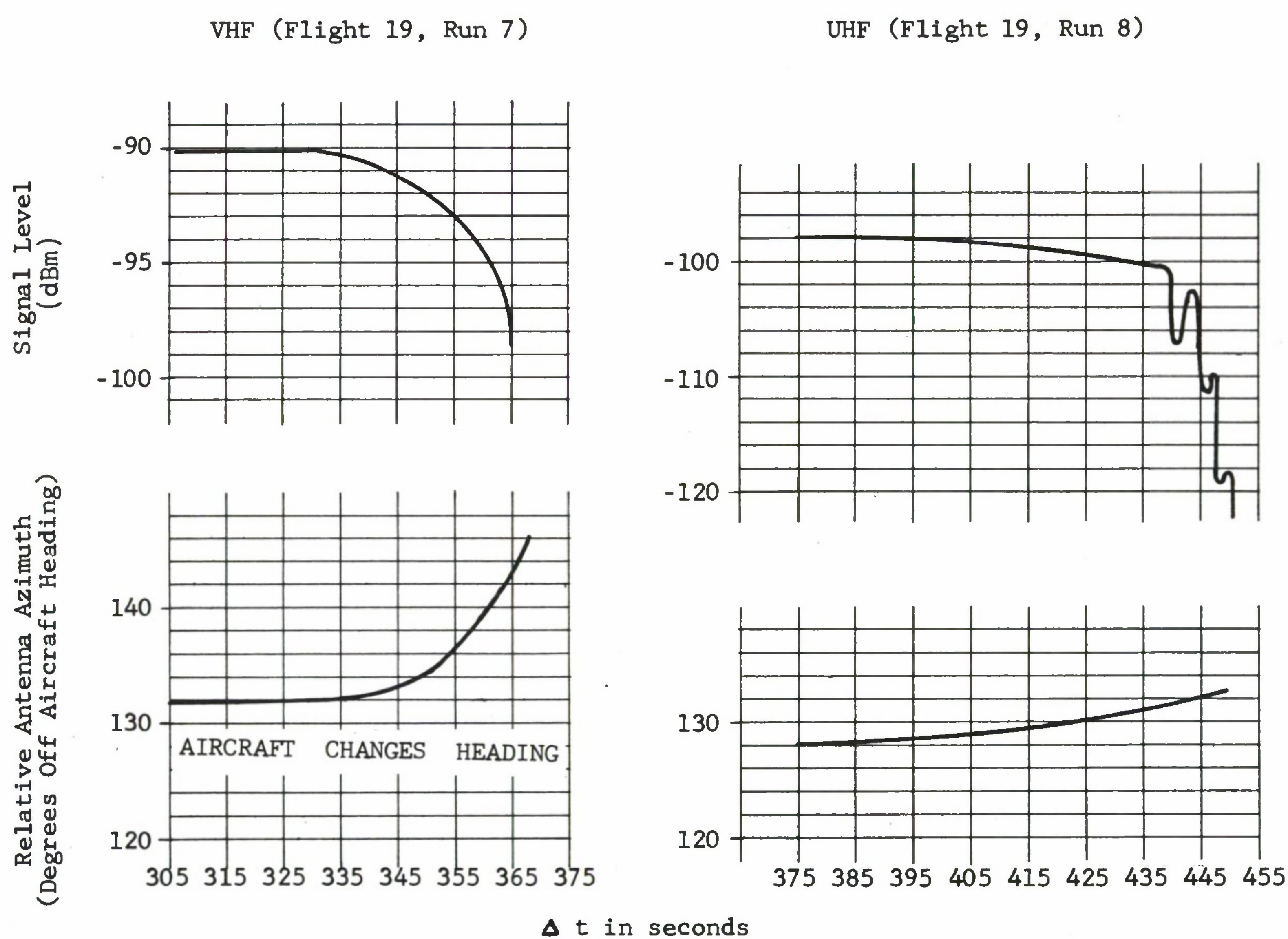
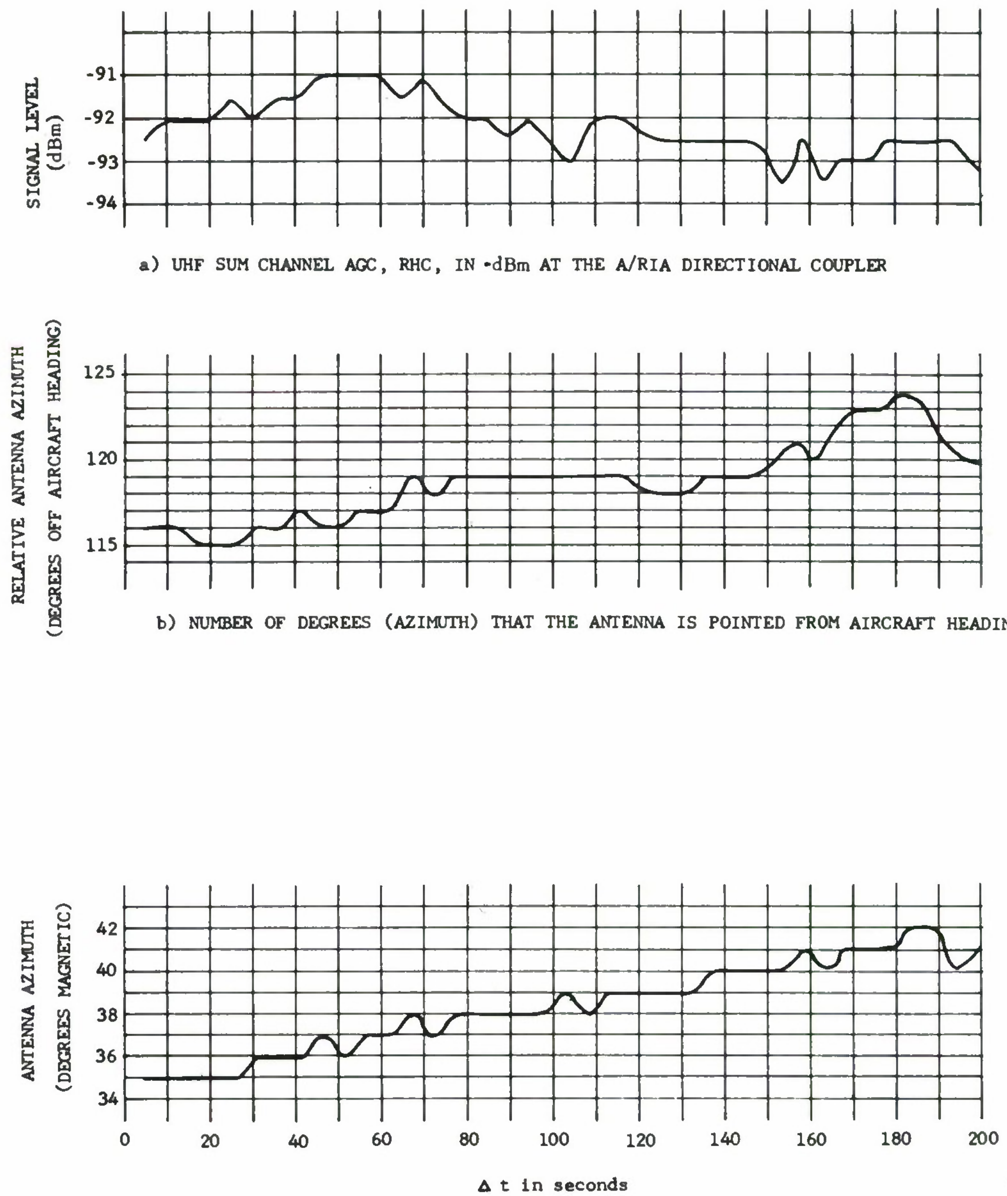


FIGURE 33. SIGNAL ROLLOFF AT AZIMUTH LIMITS



a) UHF SUM CHANNEL AGC, RHC, IN -dBm AT THE A/RIA DIRECTIONAL COUPLER

b) NUMBER OF DEGREES (AZIMUTH) THAT THE ANTENNA IS POINTED FROM AIRCRAFT HEADING

(c) MAGNETIC BEARING OF THE ANTENNA TO THE GROUND STATION

NOTE: Data Interval Between Points 3 and 5 on Ground Station Offset Flight Pattern

FIGURE 34. UHF TRACKING AT AZIMUTH LIMITS

(Flt. 30, Run 6)

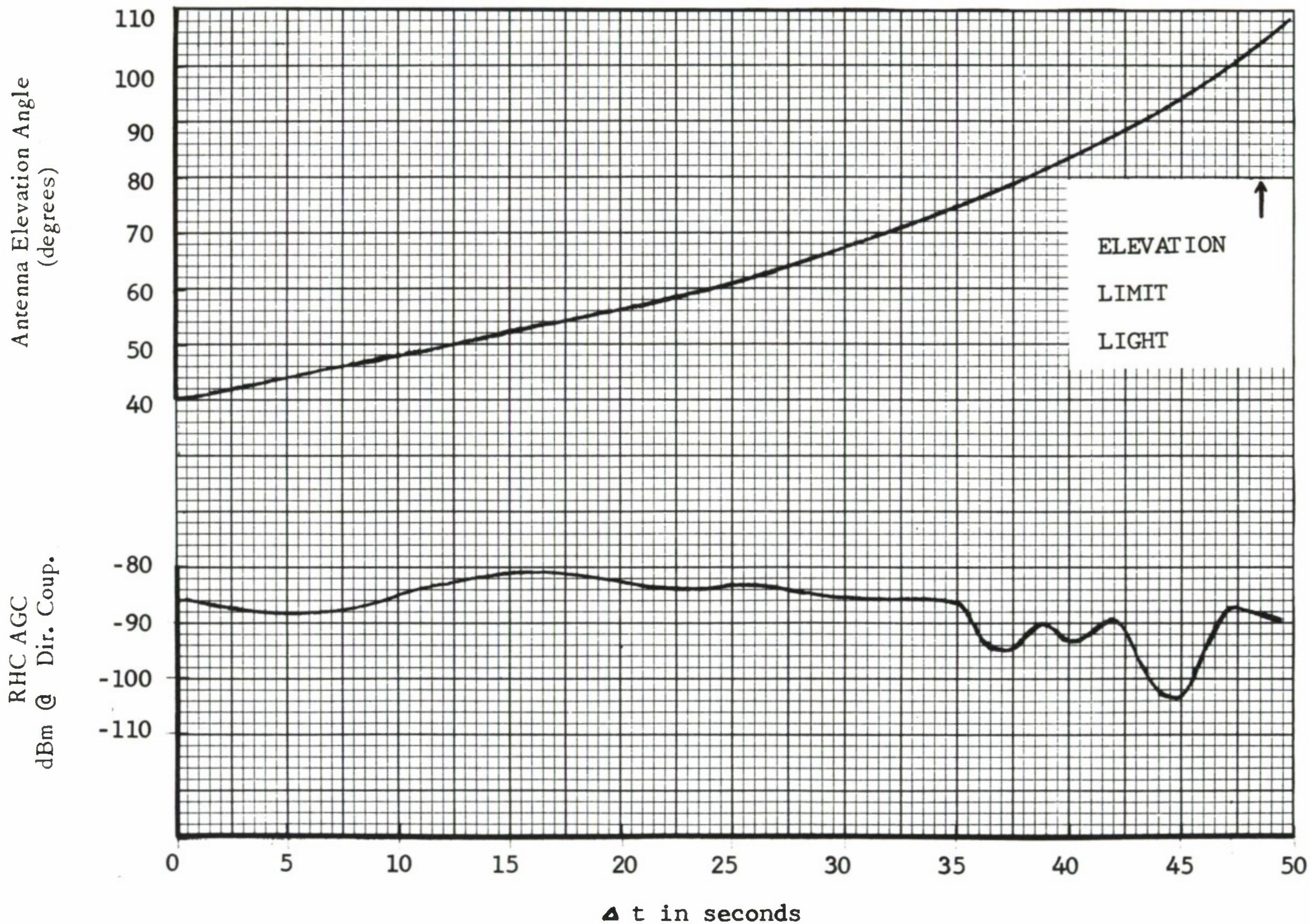


FIGURE 35. VHF TRACKING TO ELEVATION LIMITS (UPPER)

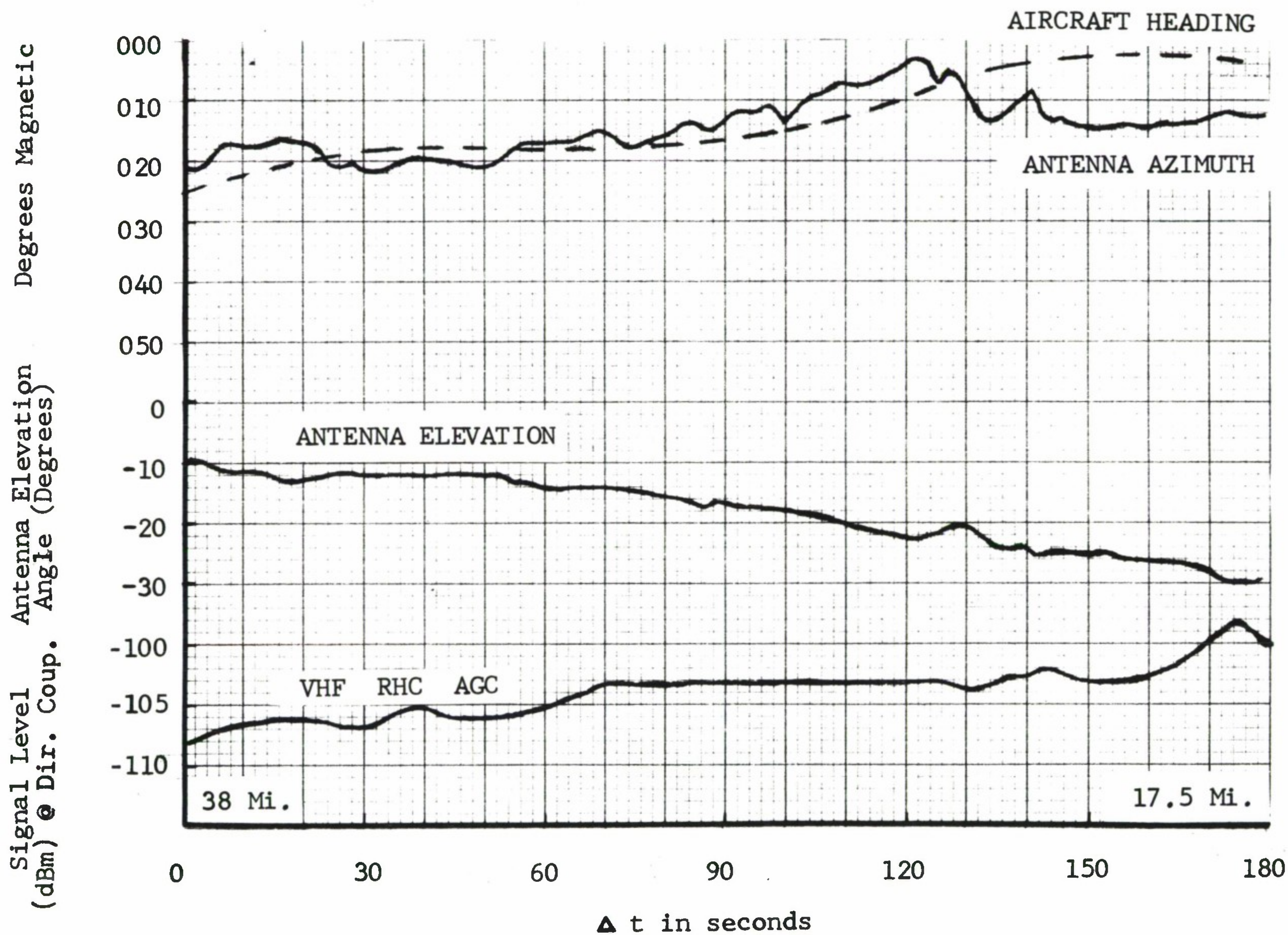


FIGURE 36. VHF LOWER ELEVATION LIMIT TRACKING

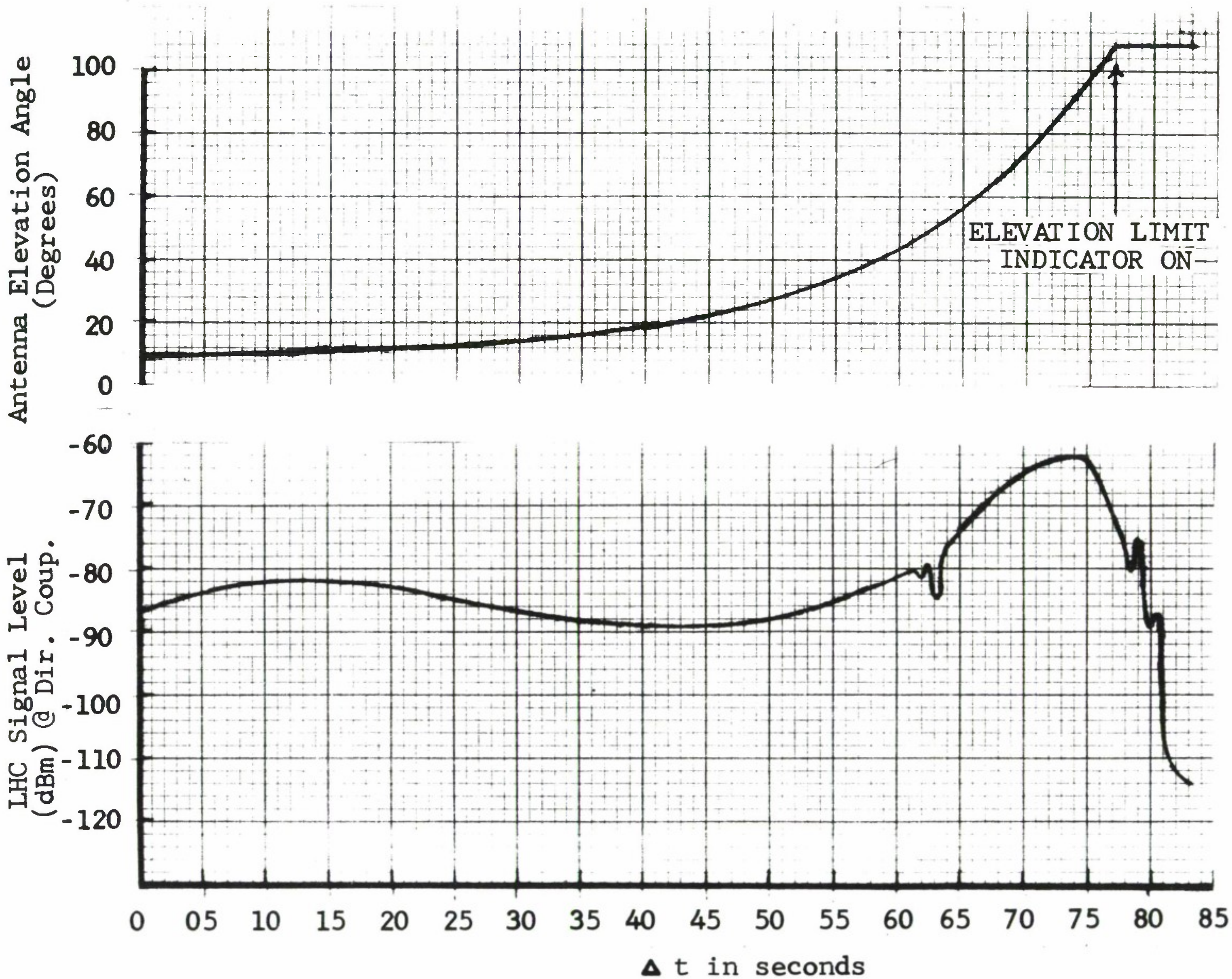


FIGURE 37. UHF TRACKING AT UPPER ELEVATION LIMITS

gained from these test results is that the system will track well beyond the specified 100°, and maintains a stable and accurate track into the mechanical limits of the antenna.

VHF Elevation Limit Tests

Figure 35 is a time history of the VHF upper elevation limit test, showing signal strength (sum channel AGC) and the antenna elevation angle up to 105°. This test was accomplished by flying a tail-chase of the NASA C-121. The pattern of the C-121 VHF antennas mounted on the bottom of the fuselage may have caused the perturbations evident from 70° to the limit. The angular tracking rate from 70° is 1.7°/second, with signal level variations up to 15 dB. This test result verifies that the system will track beyond the specified 100°, maintaining stable and accurate track up to the mechanical limit of the antenna. An elevation limit test, either upper or lower, is difficult to accomplish in the air because the A/RIA must be positioned directly under or over the signal source. An offset may result in an azimuth rather than an elevation limit.

Figure 36 is a time history of the VHF lower limit test, showing relative antenna azimuth, antenna elevation and signal strength (sum channel AGC). This test was performed by flying over the ground station. The elevation limit was reached at an elevation loop angle of -29° with respect to the horizontal. The difference between this angle and the mechanical stop at 34°, is due to the aircraft altitude of $+5^{\circ}$. This test result verified that the system will track beyond the specified -30°, and maintain stable and accurate track up to the mechanical limit of the antenna.

UHF Elevation Limit Tests

Figure 37 is a time history of the UHF upper limit test, showing the antenna elevation up to 105° and the signal strength (sum channel AGC) during the period. The test was performed by flying a tail-chase of the NASA C-121. The signal strength increase, as the A/RIA approached the elevation limit, resulted from a range decrease. The tracking rate for this test went up to 3.8°/second. Tracking stability and accuracy were measured at better than $\pm 0.5^{\circ}$ while tracking, up to the mechanical limit. Analysis of UHF sum channel AGC shows only one short term fluctuation at T+63"; this did not disturb antenna accuracy. Signal roll-off at the elevation limit is similar to that seen during the azimuth limit tests, occurring at $+105^{\circ}$, which is 5° beyond the specified limit of 100°. The UHF lower limit test was successfully performed against the ground station on Flight 31 of A/RIA 327. The aircraft flew a radial over the ground station at 11,000 feet altitude, while the UHF standard gain horn was optically pointed at the aircraft. The system tracked on UHF/RHC to a lower limit of -34°. The antenna was 3° right of aircraft heading when the limit was reached. Signal roll-off, observed on the UHF tracking receiver AGC meters, began approximately 3° before the limit. Roll-off at the limit was very fast.

These test results are taken from operator logs and observations. A UHF lower limit test had been attempted with the primary test aircraft, A/RIA 372, but was unsuccessful. Investigation revealed that the aircraft had flown out of the beam of the UHF ground station antenna prior to reaching the limit.

3.4.1.9 VHF System Performance —— Test 11

Determine acquisition threshold of a modulated VHF signal, PCM/FM, with a 300-KHz IF bandwidth and a 500-KHz IF bandwidth.

Goal

With a 300-KHz IF bandwidth, acquire a signal power of -108.6 dBm at the directional coupler. With a 500-KHz IF bandwidth, acquire a signal power of -106.4 dBm at the directional coupler.

Conditions

VHF acquisition threshold tests were performed with the ground station at Tulsa and with the NASA C-121. All tests were performed with an FM demodulator, using either a 300-KHz or a 500-KHz IF bandwidth filter. Acquisition or break lock is defined as when the Carrier Operated Relay (COR) energizes or de-energizes. When the COR is energized, the VHF system is in AUTO TRACK.

The acquisition and break lock levels with an FM demodulator in the tracking receivers occur less than 1 dB apart. These tests were accomplished by the following procedures:

a. A voice link was established between the A/RIA and the ground station or C-121 on VHF or UHF.

b. A signal several dB above the expected threshold was acquired using manual scan/automatic acquisition.

c. Once stable AUTO TRACK on VHF was established, the signal was attenuated at the source (ground station or C-121) in 1-dB steps until the AUTO TRACK light went out.

d. The signal was immediately increased until re-acquisition of AUTO TRACK.

The data used to determine the acquisition and break lock points were reduced from instrumentation records. The GMT of AUTO TRACK (ON or OFF) was taken from event recorder records and the signal strength read from the oscillograph records at the same GMT.

The theoretical acquisition level is determined as follows:

	300-KHz IF	500-KHz IF
Φkt (Noise Spectral Density, $T_{sys} = 1322^{\circ}$ K)	-167.4 dBm/Hz	-167.4 dBm/Hz
Predetection Noise Bandwidth	+ 54.8 dB	+ 57.0 dB
Predetection SNR required for AUTO TRACK	+ 6.0 dB	+ 6.0 dB
Theoretical Acquisition Threshold at Antenna Load	-106.6 dBm	-104.4 dBm
Theoretical Acquisition Threshold at the Directional Coupler	-108.6 dBm	-106.4 dBm

The COR adjustment in the VHF receivers was accomplished on the bench. The relay was adjusted to energize with a SNR of 6 dB in the IF. When flying in the racetrack pattern near Tulsa, the man-made noise went up by approximately 4 dB; however, this increase in noise did not affect the acquisition level. The COR energized when the received signal plus noise was 6 dB above the bench noise setting. The 4-dB increase in noise resulted in the COR (and AUTO TRACK) energizing when the signal was 2 dB above the noise. The increase in noise does affect data SNR and (theoretically) tracking stability, since it decreases the depth of the error channel null.

The acquisition threshold tests were performed with a carrier being modulated PCM/FM, with a deviation of $\pm$125 KHz (flights 21, 24, 29, and 31), or $\pm$39 KHz (flight 19). There is no modulation loss applicable for this test, even though the carrier is suppressed by frequency modulation. All power remains within the bandwidth of the receiver.

Test Results

a. Acquisition Threshold with a 300-KHz IF Bandwidth

Acquisition threshold tests with an FM demodulator and a 300-KHz IF bandwidth were performed on Flights 19, 29, and 31. Flights 19 and 31 were against the ground station and Flight 29 against the NASA C-121. The results are shown in Table VI.

The measured values essentially agree with those computed by link analysis for Flights 19 and 31. The median value for acquisition is -108 dBm and the mean -108.6 dBm. These test results indicate that the A/RIA can acquire a signal of 8.3×10^{-15} watts/m^2 if configured as outlined in this test. These results are accurate to $\pm$2 dB, placing the acquisition range at 1.3×10^{-14} watts/m^2 to 5.2×10^{-15} watts/m^2.

TABLE VI

VHF Acquisition Threshold (300-KHz IF Bandwidth)

Measurement Number	Acquisition Level at Directional Coupler (-dBm)	Break Lock Level at Directional Coupler (-dBm)
Flight 19, 1	-108	-109
2	-108	-109
3	-109	
Flight 29, 1	-107	-108
2	-108	-110
3	-110	
Flight 31, 1	-110	

b. Acquisition Threshold with a 500-KHz IF Bandwidth

Acquisition threshold tests with an FM demodulator and a 500-KHz IF bandwidth were performed on Flights 21 and 22 against the ground station. The results are shown in Table VII.

TABLE VII

VHF Acquisition Threshold (500-KHz IF Bandwidth)

Measurement Number	Measured Acquisition Level at Directional Coupler (-dBm)	Break Lock Level at Directional Coupler (-dBm)
Flight 21, 1	-107.5	-108.5
2	-107.5	-108.5
3	-107.5	-108.5
4	-107.0	
Flight 22, 1	-107.0	-108.0
2	-107.5	-108.0
3	-107.5	-108.0
4	-107.5	-108.0
5	-107.5	

The median value for acquisition is 107.5 dBm and the mean is -107.4 dBm. The test results indicate that the A/RIA can acquire a signal of 1.1×10^{-14} watts/m^2, if configured as outlined for this test. These results are accurate to ± 2 dB, placing the acquisition range at 1.7×10^{-14} watts/m^2 to 6.9×10^{-15} watts/m^2. The measured and theoretical values agree within the established tolerance.

3.4.1.10 VHF System Performance —— Test 12

Evaluate VHF beam tilt. Evaluate the lower portion of the VHF beam to determine the roll-off of signal caused by up-pointing at horizon acquisition (T. P. 7.4.1.C.5).

Goal

Determine signal attenuation resulting from a VHF beam tilt of 11°, 16°, 20°, and 23°. Determine contour of lower portion of antenna pattern with 0°, 11°, 16°, 20°, and 23° of beam tilt.

Conditions

The A/RIA acquired and tracked on UHF/LHC on both the beam tilt test (Flight 15, Data Run 5) and the lower beam contour test (Flight 24, Data Run 5). VHF signal power for both of these runs was set to -90 dBm at the A/RIA directional coupler, and a standard racetrack pattern was flown against the A/RIA ground station. Specific conditions for each test were as follows:

a. VHF Beam Tilt - Flight 15, Data Run 5

The A/RIA ground station transmitted a horizontally polarized signal, while the A/RIA was configured to receive circular. Receiver AGC levels used in this evaluation were from Track Receiver 1 and Telemetry Receivers 2A and 4A. Once stable track was established, the beam tilt switch was successively positioned at 11°, 16°, 20°, and 23°.

b. VHF Lower Beam Contour - Flight 24, Data Run 5

The A/RIA ground station transmitted a horizontally polarized signal, while the A/RIA was configured to receive linear. Track Receiver 1 AGC (VHF horizontal) levels were used in this evaluation. Once stable track was established, the antenna was manually swept upward through 25° with 0° of beam tilt. The antenna was manually returned to normal and the target reacquired on UHF/RHC. This procedure was repeated with beam tilt settings of 11°, 16°, 20°, and 23°.

Test Results

The desired goals were achieved.

VHF Beam Tilt

With the antenna tracking UHF and on target, signal attenuation introduced by beam tilt is shown in Table VIII.

TABLE VIII

Beam Tilt Switch Setting

	0°	11°	16°	20°	23°
Signal Power Loss	0 dB	1. 1 dB	1. 9 dB	2. 5 dB	3. 9 dB

The results show a decrease of approximately 1 dB per step, as expected. at 20° off target, the signal was measured at -2. 5 dB, very close to the nominal 3 dB at this point.

VHF Lower Beam Contours

The lower portions of the VHF antenna patterns at various electrical beam tilt settings are shown in Figure 38. In addition to target (on-axis) signal loss, these patterns indicate the magnitude of rejection to multipath signals as a function of angle below the target and are used for Apollo profile extrapolation in Section 3. 12. 3. Although the plots demonstrate relatively minor pattern distortion associated with tilting, the pattern for the 23° tilt does suggest an increased sidelobe level (only 10 dB down from the on-axis gain).

3. 4. 1. 11 VHF System Performance —— Test 13

Acquire and Track the NASA C-121 on VHF.

Goal

Demonstrate the capability of the VHF system to track a target aircraft and evaluate tracking stability and accuracy.

Conditions

The A/RIA flew the flight patterns shown in Section 3. 1. 3 during Flights 3, 6, 13, 29, and 30. Data from Flights 29 and 30 are used in this report. Flights 29 and 30 were essentially identical, the variable being that Flight 29 was over land near Tulsa and Flight 30 was over the Gulf of Mexico. The VHF tracking receivers (LHC and RHC) were configured with FM demodulators and 300-KHz IF bandwidth filters. UHF difference channel voltage outputs (Az and E error) were used to measure VHF tracking accuracy. These error voltages are more sensitive than the VHF error voltages.

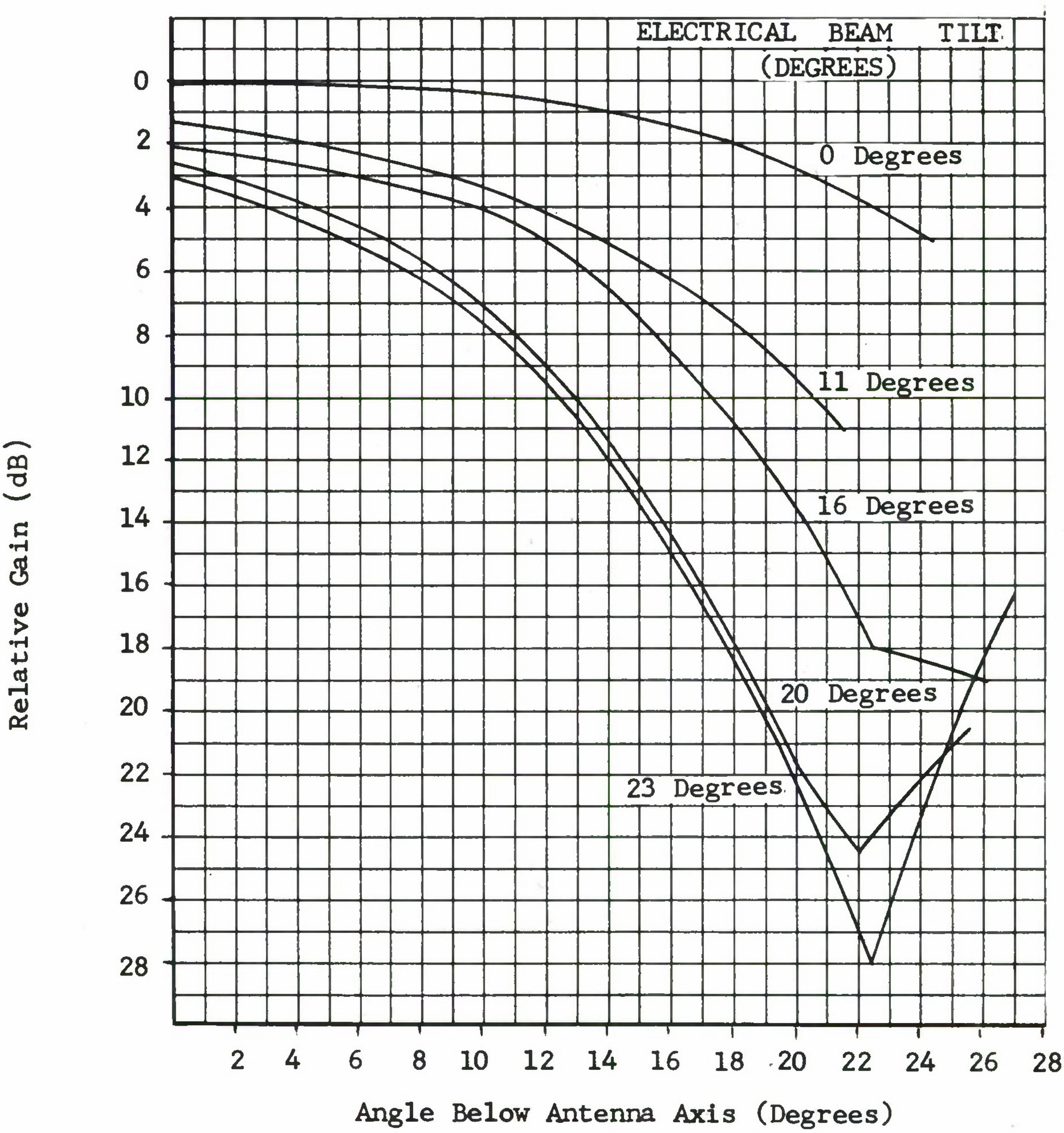


FIGURE 38. VHF LOWER BEAM CONTOURS WITH BEAM TILT

Tracking stability was determined by evaluating 10-second time slices from oscillograph records. The stability presentations show the percentage of time within the selected period that the antenna was within $\pm 2^{\circ}$, $\pm 4^{\circ}$, $\pm 6^{\circ}$, and $\pm 8^{\circ}$ of the target.

Test Results

The results of this test are discussed in the four following paragraphs, each describing a data run against the C-121. VHF tracking stability/accuracy is analyzed for each sample taken within the run.

Flight 29, Data Run 5

The target was acquired on VHF/OPT, with immediate AUTO TRACK. The signal power measured between -98 dBm and -107 dBm on VHF/RHC and between -90 dBm and -100 dBm on VHF/LHC at acquisition, with a 1-Hz multipath rate. A 10-second time slice was used to sample tracking accuracy/stability 75 seconds after acquisition (see Figure 39). During the 10-second period, the antenna remained within $\pm 2^{\circ}$ of the target in both azimuth and elevation. The signal level measured between -93 dBm and -100 dBm on the LHC channel, and between -95 dBm and -104 dBm on RHC. Some multipath was present at a 2-Hz rate.

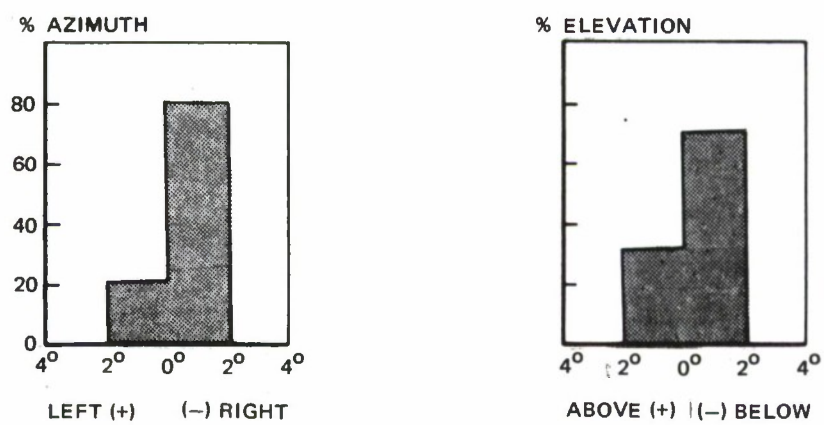


FIGURE 39. TRACKING STABILITY/ACCURACY, FLIGHT 29, RUN 5, SAMPLE 1

A second 10-second time slice was sampled midway through the run, 415 seconds after acquisition. The antenna was extremely stable during the period, as shown in Figure 40. The received signal power measured between -90 dBm and -92 dBm during the sample. Tracking stability and accuracy were checked throughout this data run. The VHF system kept the antenna within $\pm 2^{\circ}$ of the target aircraft during the entire run (1273 seconds), except for one short period while intentional Break-Lock/Acquisition tests were performed. Over 60 percent of the time during the run, the antenna was less than 1° off in azimuth and elevation. Tracking was terminated when the antenna reached the limit. The signal power measured approximately -91 dBm at the end of the run, when multipath measured approximately 11 Hz.

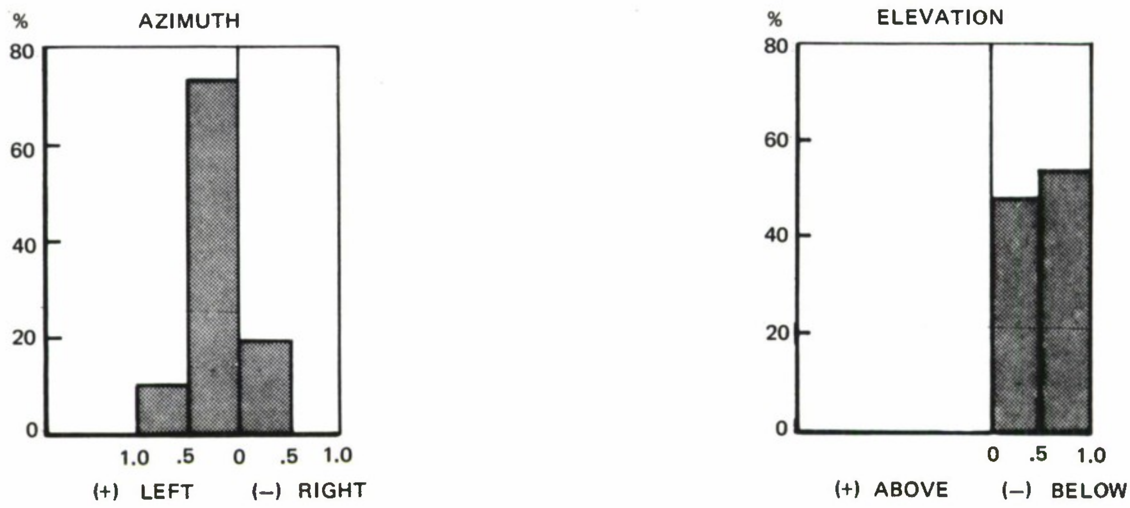


FIGURE 40. TRACKING STABILITY/ACCURACY, FLIGHT 29, RUN 5, SAMPLE 2

Flight 29, Data Run 6

The target was acquired on VHF/OPT with immediate AUTO TRACK. The system alternately selected RHC and LHC for a few seconds, then remained on RHC. A signal power of approximately -90 dBm was measured on both channels. At acquisition, the antenna position was 26° left of aircraft heading at an elevation angle of -1°. Multipath was measured at a 2-Hz rate. A 10-second time sample taken 480 seconds after acquisition showed less than 1° of error in azimuth and elevation.

A second 10-second sample was taken 606 seconds after acquisition, during a time when the VHF signal from target aircraft was intentionally attenuated to measure Acquisition/Break Lock. The level was between -106 dBm and -108 dBm. (Test 11 Test Results, show that the VHF threshold with a 300-KHz IF bandwidth filter is -108. 6 dBm, ± 2 dB.) Tracking during this period was very stable; the antenna remained within $\pm 2^{\circ}$ of the target in azimuth and $\pm 1^{\circ}$ in elevation.

A third sample was taken 718 seconds after acquisition. During this period, the received signal was varying between -92 dBm and -98 dBm. Multipath was measured at a 5-Hz rate. During the sampled period, the antenna stayed within $\pm 2^{\circ}$ of the target aircraft in azimuth and elevation error reached 4°.

The last sample was taken at 863 seconds after acquisition. The A/RIA was close to the C-121 at this time, being slightly behind and to the right of it. The received signal level was varying between -95 dBm and -100 dBm, with a multipath frequency of 11-Hz. The antenna remained within 0° to 2° left of the target in azimuth and within 0° to 1° above in elevation, as shown in Figure 41.

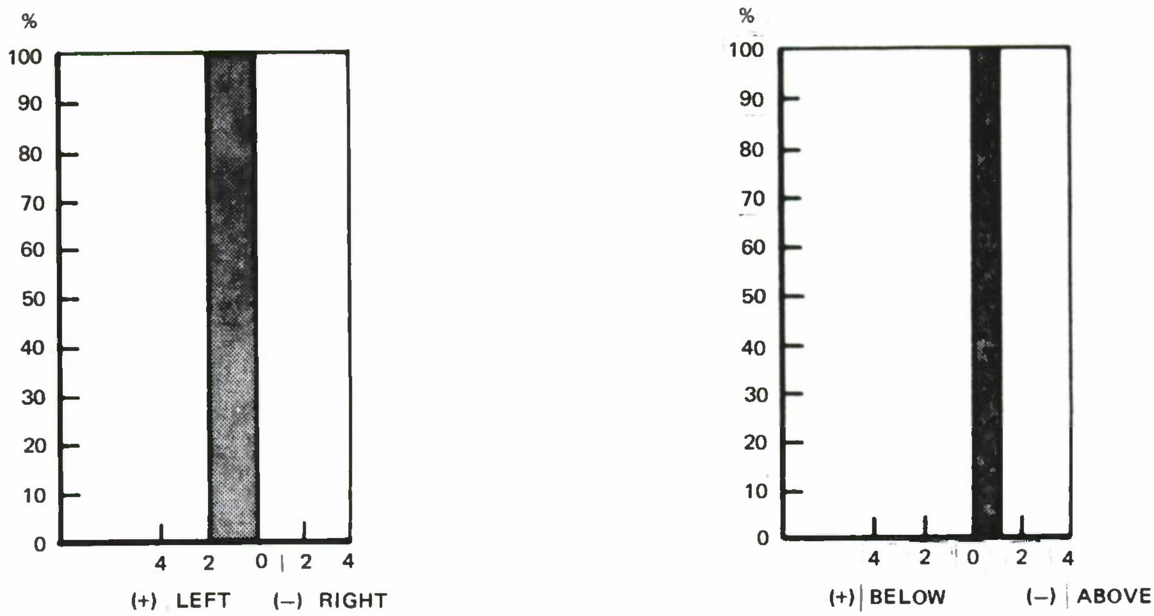


FIGURE 41. TRACKING STABILITY/ACCURACY, FLIGHT 29, RUN 6

During all but a few seconds of this 15-minute data run, the VHF tracking system kept the antenna within the UHF beamwidth of $\pm 2^{\circ}$. In deference to a marginal UHF signal throughout the run, the UHF receivers did not break lock.

Flight 30, Data Run 6

The target was acquired on VHF/OPT with immediate AUTO TRACK. The system alternately tracked on the RHC and LHC channels, although RHC was predominant. Flight 30 was over water, and the aircraft pattern was designed to maximize multipath.

The signal level early in the run measured approximately -100 dBm, with up to 10 dB of multipath at a frequency of about 1 Hz. The first 10-second sample was taken 370 seconds after acquisition. During this period, the signal level was varying between -97 dBm and -104 dBm at a 1-Hz rate. The antenna elevation was 2° up. Figure 42 shows the tracking stability/accuracy during the sampled period. With multipath present, the system tracked within $\pm 2^{\circ}$ in azimuth 95 percent of the time, and within $\pm 2^{\circ}$ in elevation 93 percent of the time.

A second sample was taken 780 seconds after acquisition. Antenna elevation remained at approximately 0° up, whereas multipath fades measured 10 dB at a rate of 6 Hz. The antenna accuracy was degraded, with elevation errors of up to 12° (below target) and azimuth offset of 3°. Analysis of the data provides no correlation between these antenna excursions and the high multipath.

A third sample at acquisition plus 1190 seconds represents the 10-second period just preceding the antenna reaching the upper limit. The elevation was approximately $+100^{\circ}$. Under extremely high rates (10°/second Az, 1°/second E), the antenna remained less than 4° off of the target.

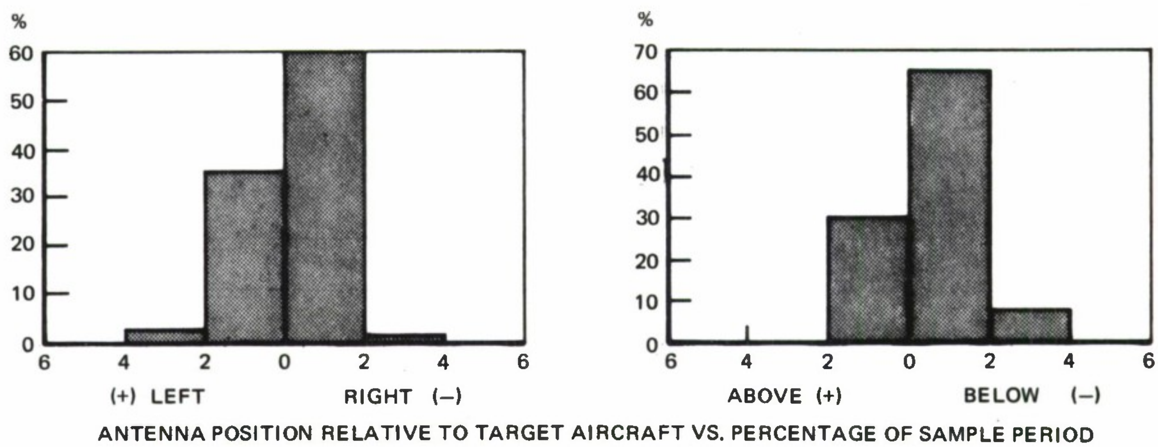


FIGURE 42. TRACKING STABILITY/ACCURACY, FLIGHT 30, RUN 6, SAMPLE 1

Flight 30, Data Run 5

This data run was performed to evaluate tracking stability and accuracy near the antenna limit, but provided excellent data for evaluating overall tracking capability. The duration of the run was 1403 seconds from initial acquisition to LOS. Antenna position versus target position was evaluated for the entire run, and tracking accuracy was $\pm 2^{o}$ during 95.5 percent of the time. (Break-Lock/Acquisition tests were performed during the run, taking 123 seconds. This period was not counted when the 95.5 percent figure was derived.) Three times during the latter portion of the run, over a 55-second period, the antenna drove to the lower limits. Each time it recovered after approximately 4-seconds. During this 55-second period, the measured signal power was between -81 dBm and -92 dBm, with multipath of approximately 5 dB at 6-Hz rate. Analysis of the oscillograph records shows that the UHF error voltage fluctuation precedes a drop in UHF sum channel AGC. Investigation of this anomaly thus far has tentatively correlated the three tracking excursions with keying of the HF transmitter transmitting on the trailing wire antenna. The frequency being used was 13.218 MHz. Subsequent investigation of this problem indicates that the UHF/VHF antenna servo system is susceptible to HF transmissions at frequencies above 9 MHz from the trailing wire antenna. This problem was resolved by the incorporation of EP 0071, which added an RF filter to the antenna control circuitry, OA-11. The adequacy of the ECP was verified by flight test on aircraft 61-330 on 9 August 1967.

3.4.1.12 VHF System Performance —— Test 14

Evaluate tracking characteristics at VHF (linear polarization).

Goal

Evaluate tracking accuracy and stability while receiving signals polarized vertically, horizontally, and slant linear.

Conditions

Data Runs 1, 2, and 3 of Flight 24 were flown to evaluate VHF tracking in linear polarization. The A/RIA flew a pattern similar to that shown in Figure 43; this pattern was designed especially for these tests to provide tracking up to $\pm 90^o$ from aircraft heading in a controlled signal environment. The VHF signal power for these tests was approximately -90 dBm at the A/RIA directional coupler. A UHF signal was being received at a nominal -105 dBm at the A/RIA directional coupler. Calibrated UHF Az and E error voltages were used to measure tracking stability and accuracy. The only difference in conditions between Runs 1, 2, and 3 was the polarization of the signal being transmitted from the A/RIA ground station; Run 1 was vertical, Run 2 was horizontal, and Run 3 was slant linear (45^o).

Test Results

Data Run 1, Signal Source Vertically Polarized

During Data Run 1, the system tracked on VHF/vertical. Figure 44 is a plot of the middle one-half of the actual data run when the aircraft made a 180^o turn. Aircraft heading and antenna azimuth and elevation position are shown during this period. The aircraft flew a constant rate turn of 1.2^o/second while the antenna position to aircraft heading changed from 90^o right to 90^o left. The azimuth and elevation plots indicate that tracking was stable throughout the period. Tracking accuracy/stability was sampled for three 10-second periods, one when the antenna was 90^o right, the second at 00^o, and the third at 90^o left. The time samples are annotated as A, B, and C on Figure 44, and are shown graphically in Figure 45. Stability and accuracy are satisfactory; the antenna remained within $\pm 2^o$ of the target during 90 percent of the run.

Figure 46 is a plot of received signal power versus the azimuth antenna position relative to aircraft heading. The system tracked a vertically polarized signal in VHF/vertical mode. The maximum received signal on the vertical channel and minimum received signal on the horizontal channel occurred at 13^o left of aircraft heading, rather than at 000^o, because the aircraft was in a bank while making the 1.2^o/second turn; therefore, the dipoles were tilted. The data indicate that the axial ratio is greater than 25 dB. The horizontal and vertical signal levels at the 90^o azimuth points are approximately equal, since the dipole is 55^o. The results compare favorably with the analysis given in TN 0164, Appendix III.

Data Run 2, Signal Source Horizontally Polarized

During Data Run 2, the system tracked on VHF/horizontal. Figure 47 is a plot of the middle one-half of the actual data run when the aircraft made a 180^o turn. During this run, the turn rate was 1.4^o/second. The spiral-type excursions, which were not present on the preceding run, were probably caused by improper phasing of the horizontal receiver. Ten-second time slices were taken to evaluate stability/accuracy, and are shown in Figure 48. These time periods are annotated as A, B, and C on the Figure 47. From 1859:20 to the end of the run, the antenna remained within $\pm 2^o$ of the target

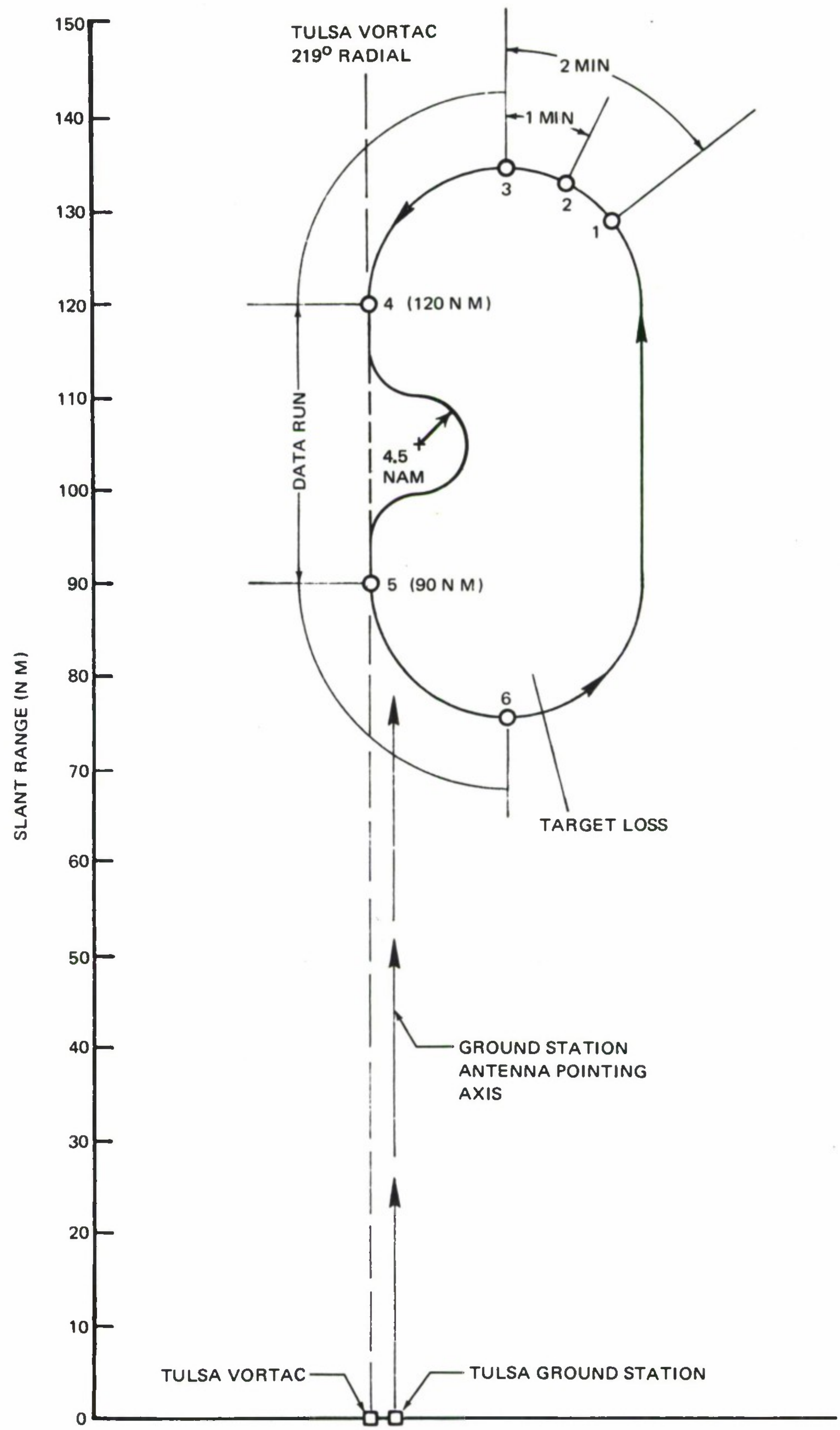


FIGURE 43. TULSA GROUND STATION SPECIAL FLIGHT PATTERN

Ground Station Antenna Vertical
Track VHF Linear (RCVR 3 Vertical)

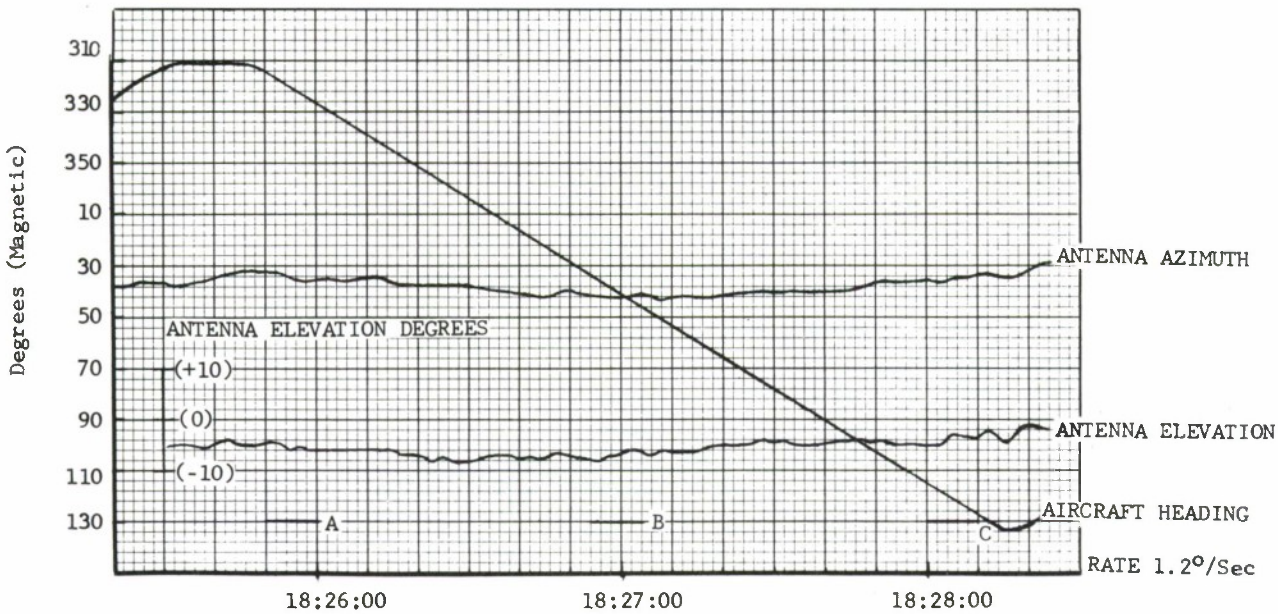


FIGURE 44. TRACK LINEAR, SOURCE VERTICAL

80% of the time. The tracking stability time slices for periods A and C are a result of improper phasing.

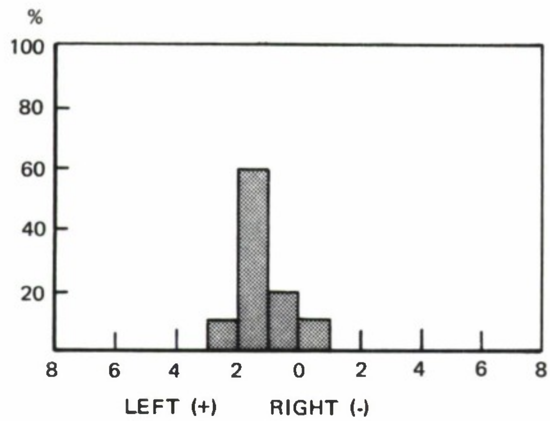
Figure 49 is a plot of received signal power versus the antenna azimuth position relative to aircraft heading. The maximum received signal on the horizontal channel and the minimum received signal on the vertical channel occurred at 11° left of aircraft heading, rather than at 000°, because the aircraft was in a bank making the 1.4°/second turn. The axial ratio is again greater than 25 dB.

Data Run 3, Signal Source Polarized Slant Linear (45°)

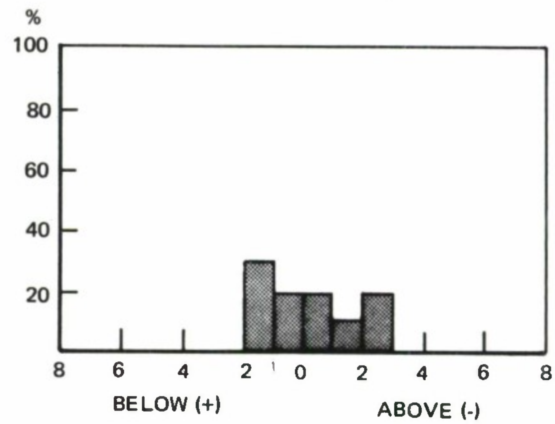
During Data Run 3, the system tracked on VHF/optimum. Figure 50 is a plot of the middle one-half of the actual data run, when the aircraft made a 180° turn. The turn rate is computed to be 1.4°/second. Tracking was stable and accurate, with the antenna remaining within $\pm 2^{\circ}$ of the target during 95 percent of the run. Three 10-second time slices were evaluated for stability/accuracy, and are shown in Figure 51.

Figure 52 is a plot of the received signal power of the horizontal and vertical channel versus the antenna position relative to aircraft heading. The crossover point in

A) ANTENNA 70° TO 80° TO THE RIGHT OF AIRCRAFT HEADING

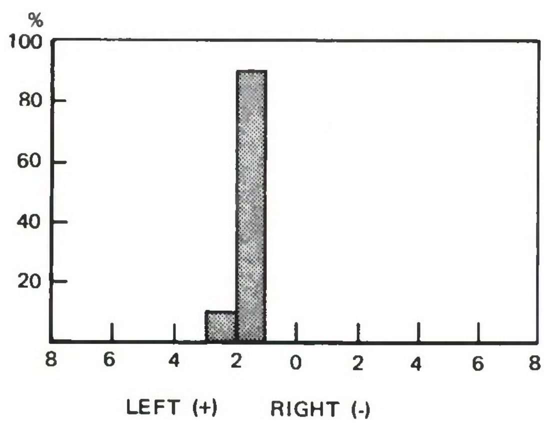


AZIMUTH TRACKING STABILITY

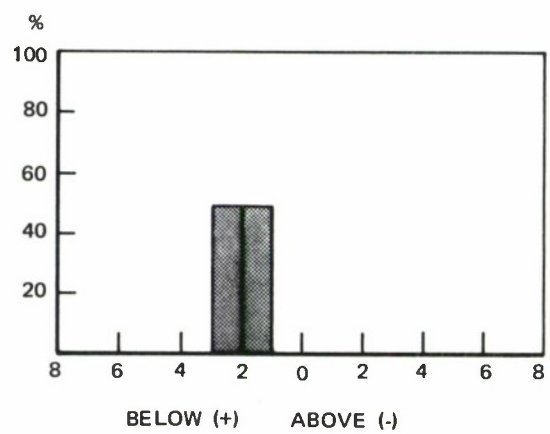


ELEVATION TRACKING STABILITY

B) ANTENNA 000° TO AIRCRAFT HEADING

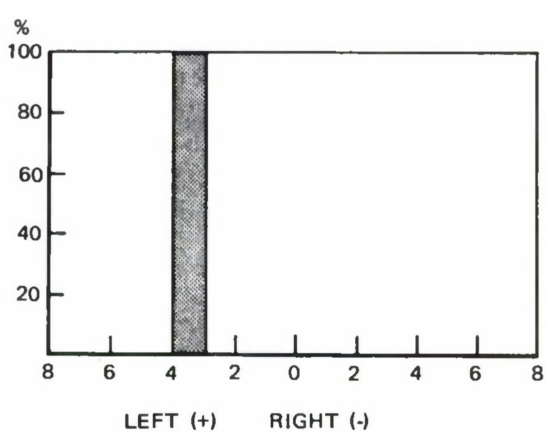


AZIMUTH TRACKING STABILITY



ELEVATION TRACKING STABILITY

C) ANTENNA 80° TO 90° TO THE LEFT OF AIRCRAFT HEADING



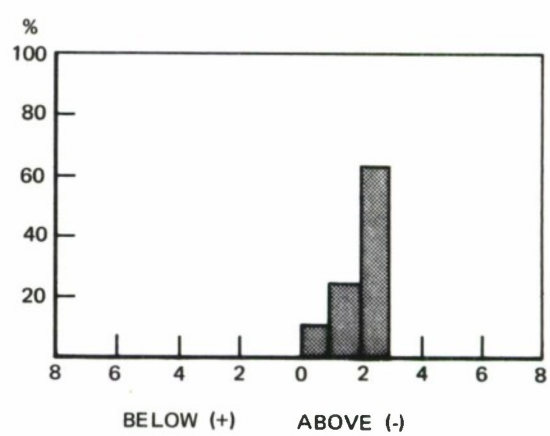


FIGURE 45. TRACK STABILITY SAMPLES, SOURCE VERTICAL

Received Signal Power vs. Antenna Position (Az) Relative to Aircraft Heading. System Tracking on Track Rcvr 3, VHF Vertical
(Flt. 24, Run 1)
Ground Source Ant: Vertical

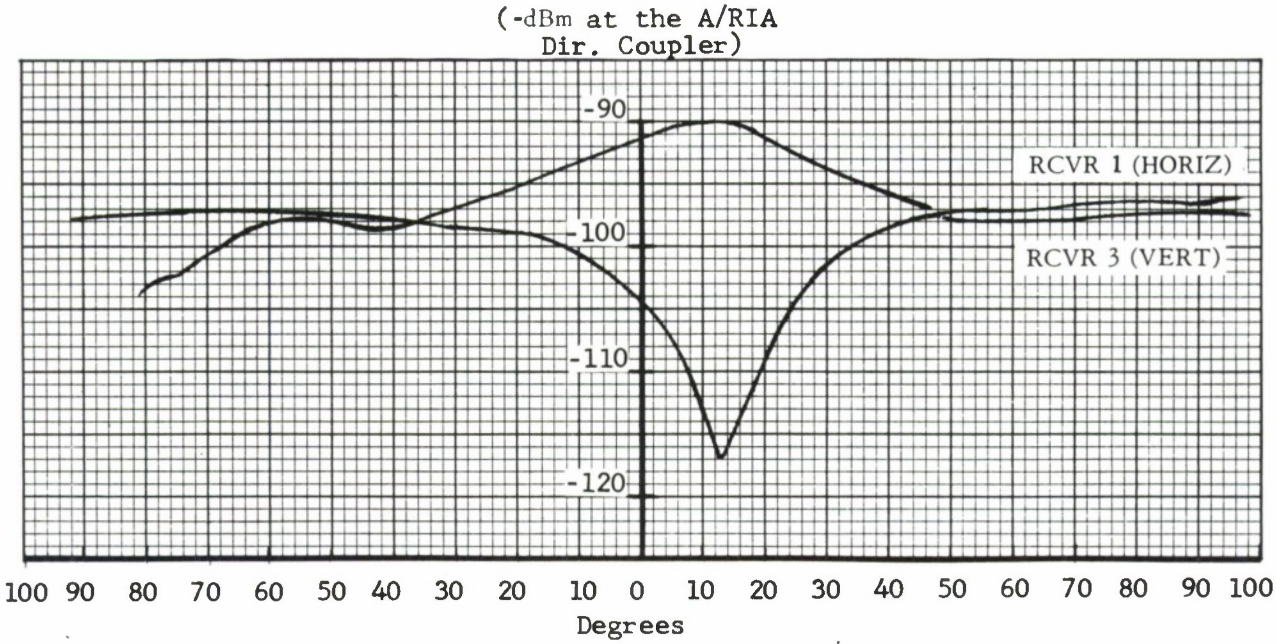


FIGURE 46. SIGNAL ROLLOFF VS ANTENNA POSITION, SOURCE VERTICAL

received signal power, horizontal and vertical, occurs at 11° left; again, this is the result of the aircraft being in a bank to negotiate the 1.4°/second turn. The asymmetrical positions of the polarization nulls are also due to the aircraft bank. This is shown analytically in Tech Note A 0164 (Appendix III). The difference in axial ratios of the two channels is attributed to amplitude and phase shifts between the horizontal and vertical components due to ground reflections. These reflections can also cause slight shifts in null positions.

3.4.1.13 VHF System Performance —— Test 15

Evaluate effect of ellipticity when receiving on VHR circular polarization.

Goal

Determine the effect of aircraft structure/radome on VHF antenna ellipticity.

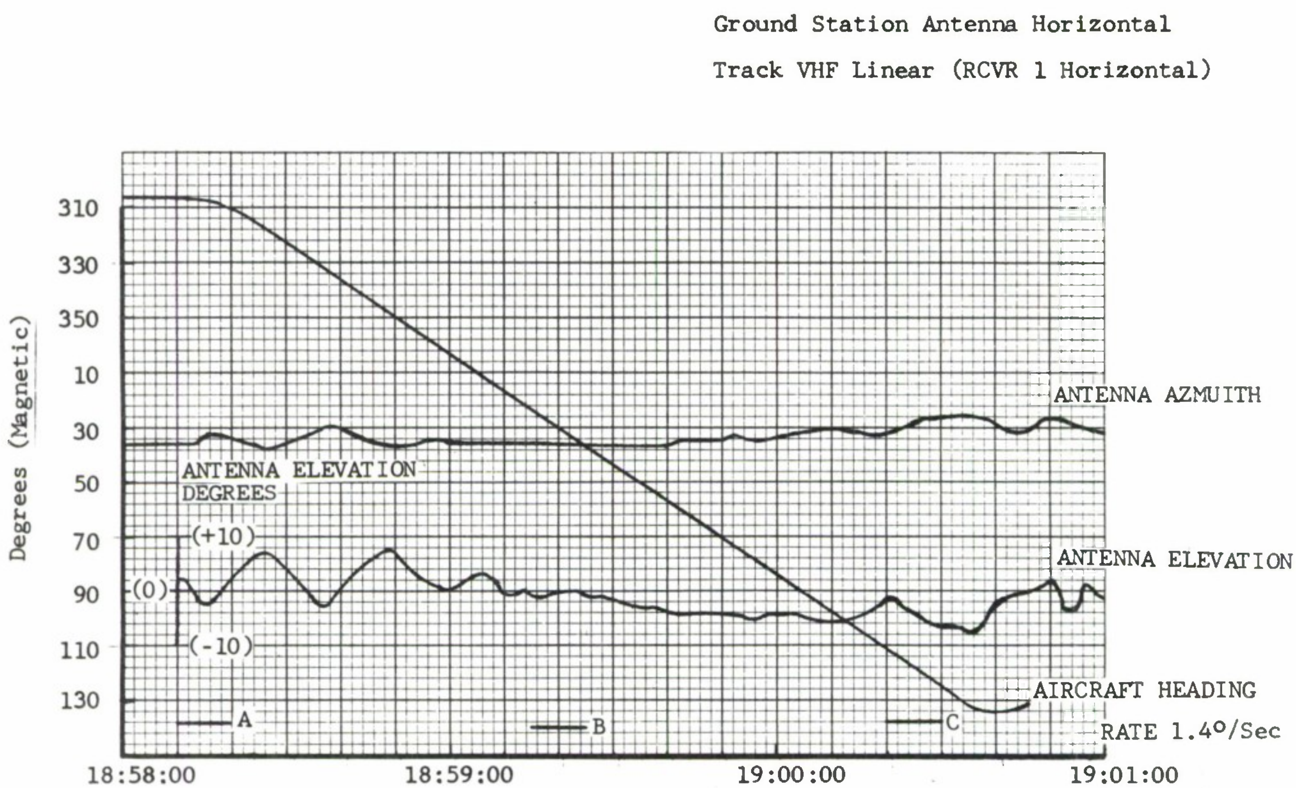


FIGURE 47. TRACK LINEAR, SOURCE HORIZONTAL

Conditions

Data Runs 1 and 2 of Flight 25 were flown to evaluate ellipticity in the receive pattern. The A/RIA flew a pattern similar to that shown in Figure 43; this pattern was designed to maximize any differences between the LHC and RHC channels while receiving a linearly polarized signal. Signal power during these runs was nominally about -100 dBm. The only difference between Runs 1 and 2 was that during Run 1 the ground station source antenna was vertically polarized and during Run 2 it was horizontally polarized.

Test Results

Data Run 1, Signal Source Vertically Polarized

Figure 53 shows the difference in received signal strength between the LHC and RHC channels plotted against the antenna heading relative to the aircraft nose. The data are from the LHC and RHC channels of two telemetry receivers. For this test, the ground station source antenna was vertically polarized.

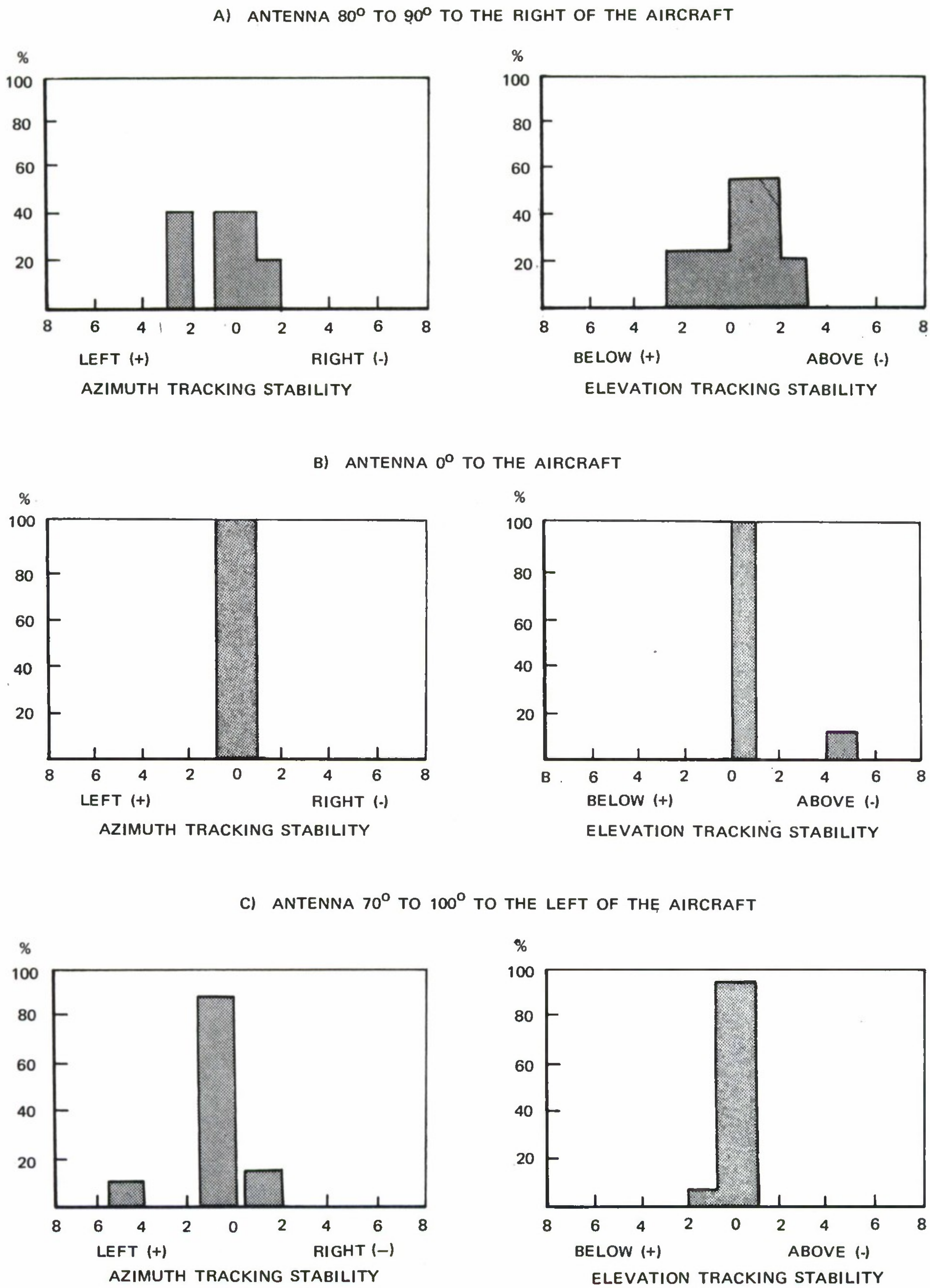


FIGURE 48. TRACK STABILITY SAMPLES, SOURCE HORIZONTAL

Received Signal Power vs. Antenna Position (Az) Relative to Aircraft Heading. System Tracking on Track RCVR 1, VHF Horizontal
Ground Station Source: Horizontal (Flt 24, Run 2)

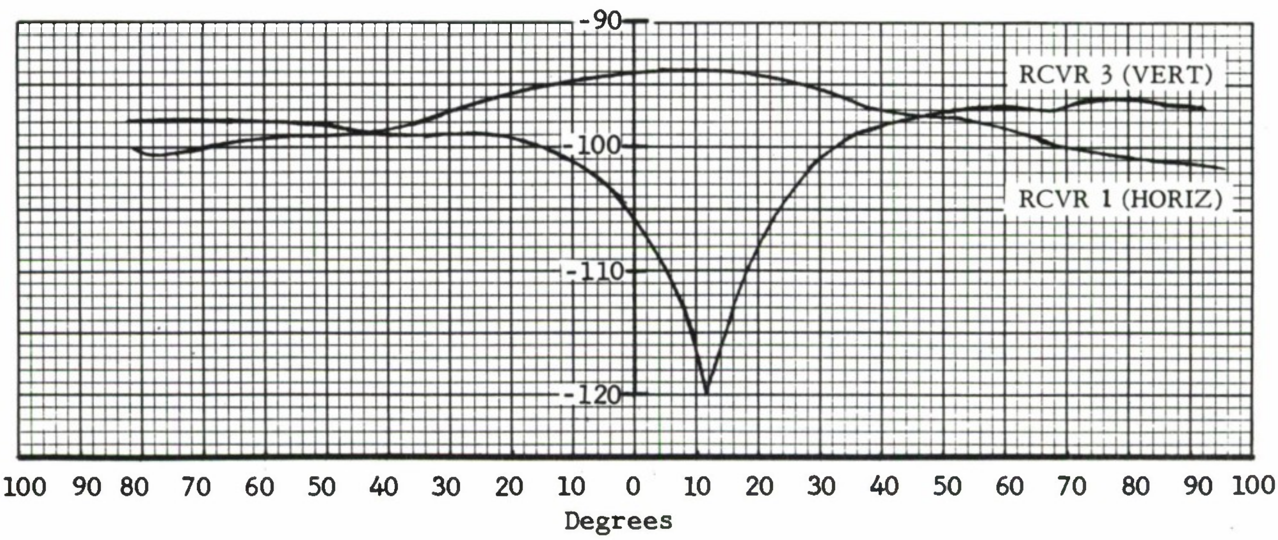


FIGURE 49. SIGNAL ROLLOFF VS ANTENNA POSITION, SOURCE HORIZONTAL

Analysis of these data shows no discernible ellipticity in the received signal pattern. The minor perturbations shown do not follow any pattern; at headings where LHC is above RHC on Receiver 4, the opposite is true on Receiver 1. The calibration accuracy of the different receiver channels precludes comparison of channels closer than 1 dB.

Data Run 2, Signal Source Horizontally Polarized

Figure 54 is similar to the plot of Figure 53, except that the received signal is horizontally rather than vertically polarized. The LHC changes relative to RHC appear to be similar on the two receivers; however, ellipticity is essentially not discernible.

3.4.2 Acquire and Track at UHF

3.4.2.1 UHF Test Result Summary

Acquisition and tracking on UHF was successfully accomplished during Category II. The acquisition threshold of UHF, Unified S-Band, 1000-Hz plase-lock loop, is 1.1 X 10^{-15} watts/m^2. The threshold of UHF (S-Band) with an FM demodulator and a 300-KHz IF bandwidth is 4.0 X 10^{-15} watts/m^2. Tests at L-Band with an FM

Ground Station Antenna
Slant Linear (45°)

Track Linear VHF Optimum
RCVR 3 (Vertical Tracking)

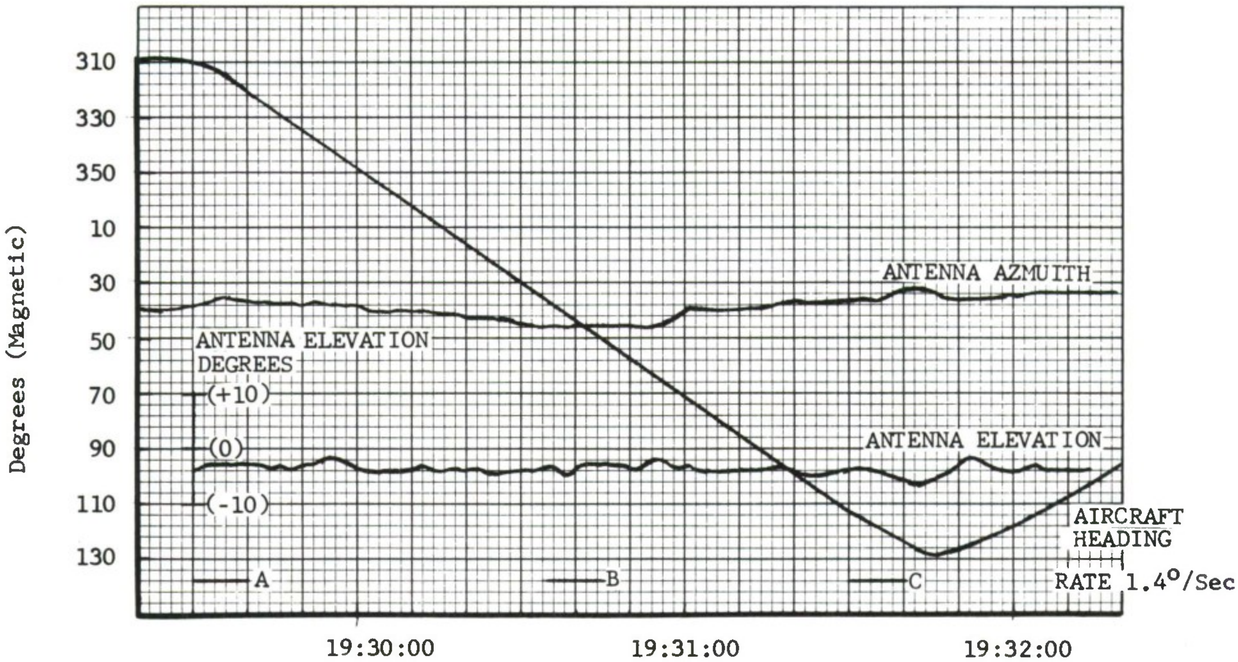


FIGURE 50. TRACK LINEAR - SOURCE SLANT LINEAR

demodulator and a 300-KHz IF bandwidth show an acquisition threshold of 2.0 X 10^{-14} watts/m^2. UHF tracking stability proved to be excellent, with long term drift less than $\pm 0.5^{\circ}$. Tracking stability was evaluated against the ground station and the NASA C-121. The UHF receive pattern sidelobes were found to be 10° from the main lobe, at a power of 18 dB to 21 dB down from the main lobe. Rate memory operation was as expected, with an accumulated error of 0° to 2° after a memory period up to 9.6 seconds.

3.4.2.2 UHF Tests Performed

Test 1 Evaluate UHF acquisition tracking stability against a ground signal source.

Test 2 Acquire and track the C-121 at UHF.

Test 3 Acquisition on a UHF sidelobe.

Test 4 Determine the acquisition threshold of a modulated Unified S-Band signal, with a 3.3-MHz IF bandwidth (data) and a 1000-Hz tracking loop bandwidth.

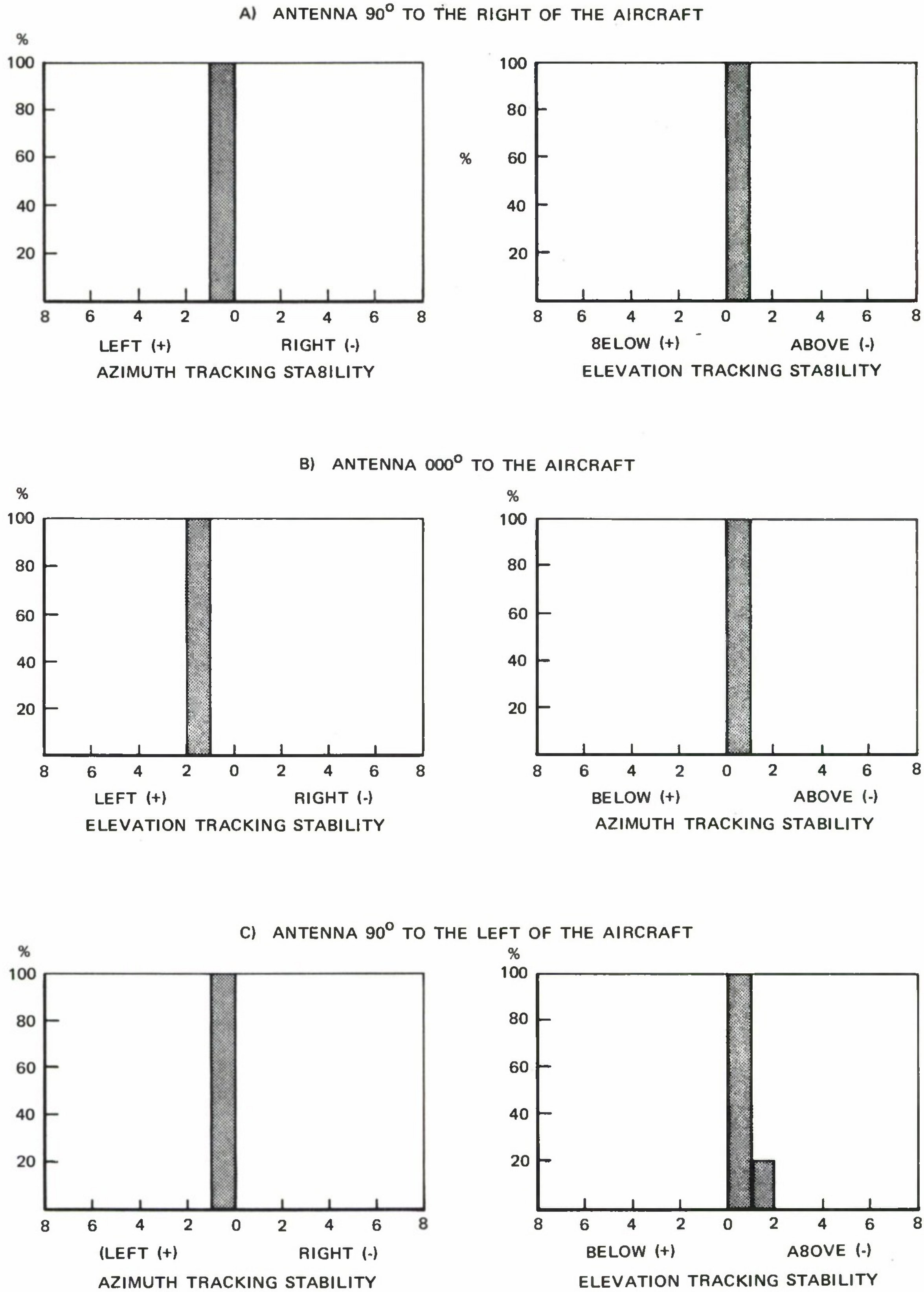


FIGURE 51. TRACK STABILITY SAMPLES, SOURCE SLANT LINEAR

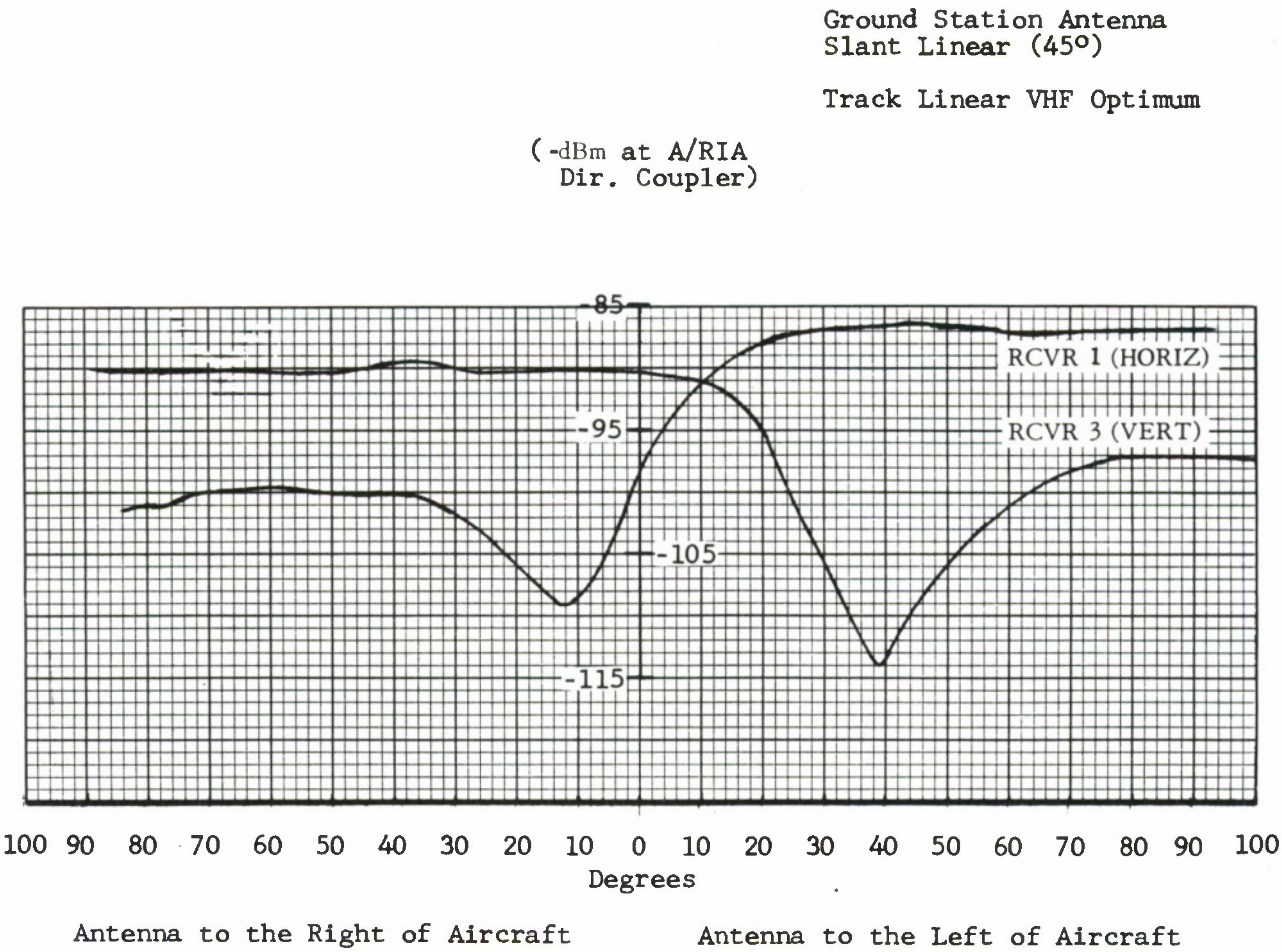


FIGURE 52. SIGNAL ROLLOFF VS ANTENNA POSITION, SOURCE SLANT LINEAR

Test 5 Determine the acquisition threshold of a modulated UHF (S-Band) carrier, PCM/FM, with a 300 KHz IF bandwidth filter.

Test 6 Determine the acquisition threshold of a modulated UHF (L-Band) carrier, PCM/FM, with a 300 KHz IF bandwidth filter.

Test 7 Acquire and track at UHF (L-Band).

Test 8 Evaluate rate memory operation, UHF and VHF.

3.4.2.3 Test Environment

The A/RIA acquired and tracked at UHF against the Tulsa ground station and the NASA C-121 during Category II. A discussion of these facilities, and the control of signals transmitted from them, is included in Sections 3.1.4 and 3.1.5, respectively. The

A/RIA VHF System - Circular
(Flt. 23, Data Run 1)

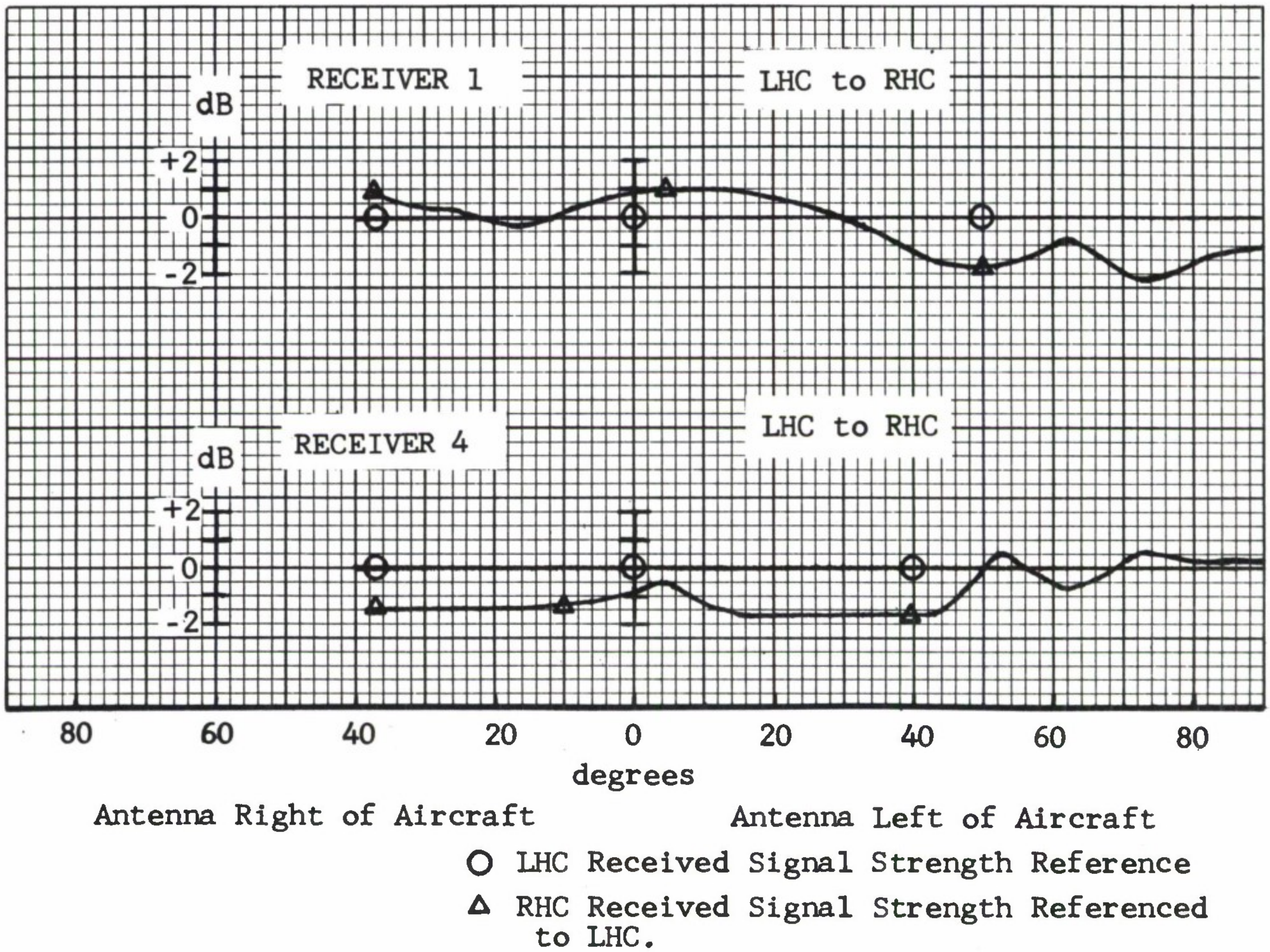


FIGURE 53. VHF RECEIVE SYSTEM ELLIPTICITY, SOURCE VERTICAL

A/RIA flew the various patterns outlined in Section 3.1.3. The environment peculiar to each test performed is covered under the Conditions paragraph of the test discussion.

3.4.2.4 Data Collection Techniques

The data collection techniques for UHF tracking are the same as those discussed under VHF tracking (see Section 3.4.1.4).

3.4.2.5 System Configuration

The A/RIA PMEE configuration used during UHF tracking tests is shown in Figure 55. The signals were received at the UHF antenna, amplified by the two difference channel TWT amplifiers, and fed to the RHC and LHC tracking receivers. The Az and E error signal receiver outputs were routed to the tracking combiner. If the system is

A/RIA VHF System - Circular

(Flt. 23, Data Run 2)

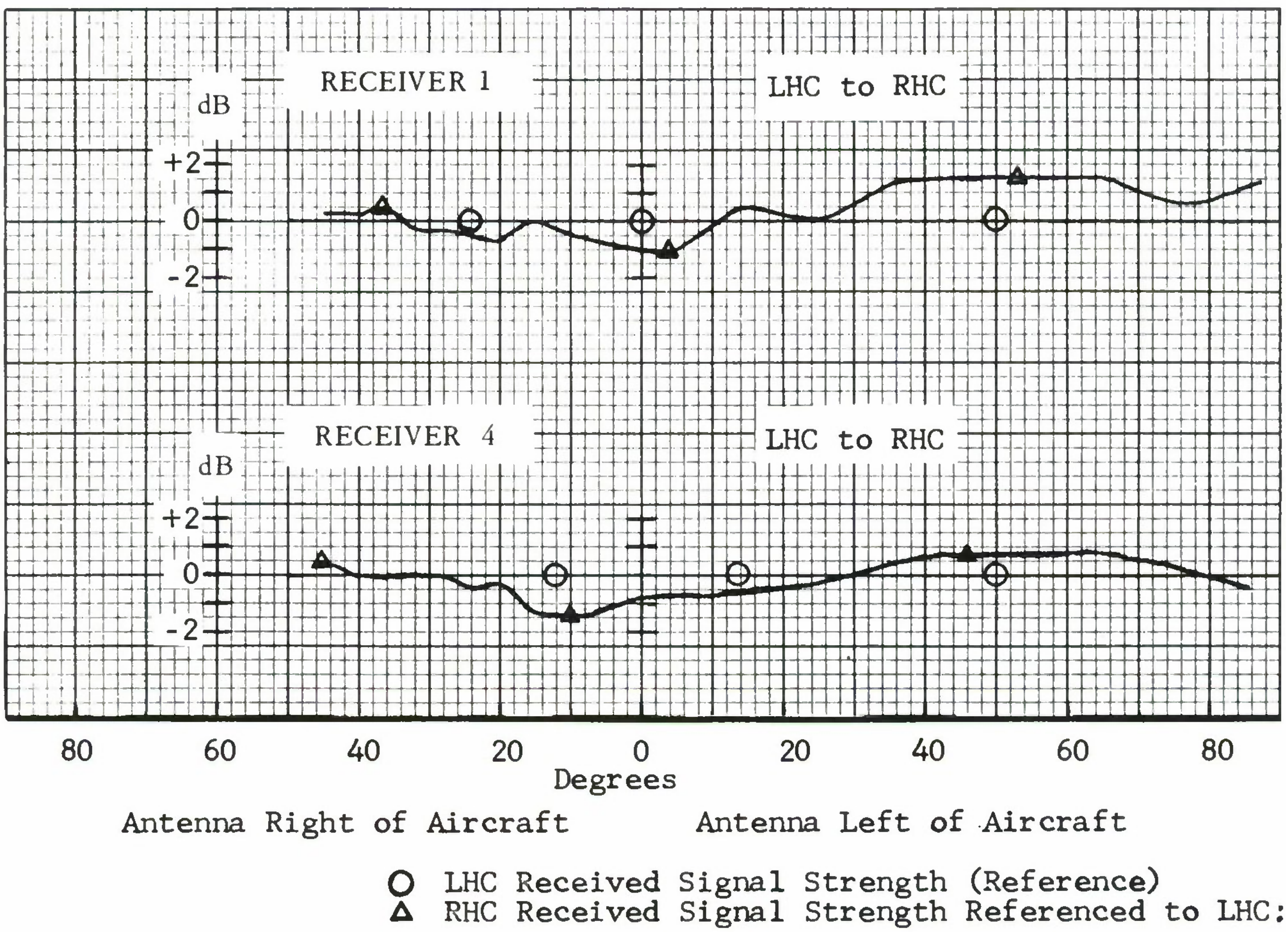


FIGURE 54. VHF RECEIVE SYSTEM ELLIPTICITY, SOURCE HORIZONTAL

is in AUTO TRACK, the selected channel (UHF/RHC or UHF/LHC) is fed to the antenna servo, automatically keeping the antenna pointed at the target. If the system is in MANUAL TRACK, the coordinate converter holds the antenna to the magnetic heading set in by the operator.

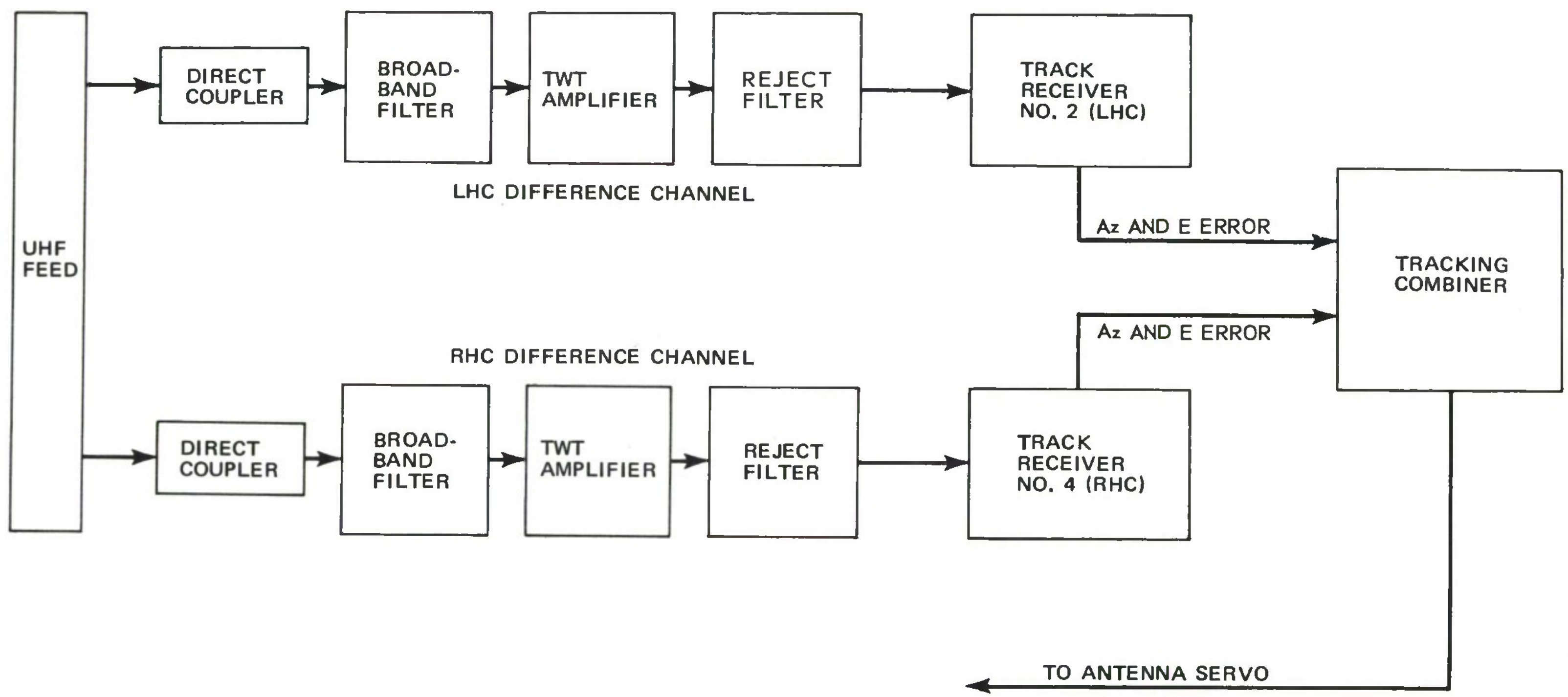


FIGURE 55. A/RIA PMEE SYSTEM CONFIGURATION FOR UHF TRACKING

3.4.2.6 UHF System Performance —— Test 1

Evaluate UHF acquisition and tracking stability accuracy against a ground signal source.

Specification/Goal

Determine acquisition characteristics and UHF tracking stability.

Conditions

The A/RIA flew a normal racetrack pattern against the ground station for these tests. The UHF system tracked on Unified S-Band on Flights 18 and 20 (1000-Hz tracking loop bandwidth) and with an FM tracking demodulator on Flight 19. Sector scan parameters used for these tests were:

Az Sector:	$\pm 4^{\circ}$	E Increment:	3.2°
Az Rate:	4°/second	E Steps:	2

Test Results

Acquisition was evaluated by analyzing the time required to acquire using sector scan, automatic acquisition, and by measuring the time required for the antenna to stabilize at a specific heading. UHF tracking stability/accuracy was evaluated by analyzing tracking performance on five data runs. Stability/accuracy was evaluated by analyzing UHF Az and E error signals, antenna relative heading and sum channel AGC, and correlating these with discrete events.

Descriptions of the five data runs are contained in the following paragraphs.

Flight 18, Data Run 5

The signal was acquired and the tracking system went into AUTO TRACK 13.7 seconds after sector scan was started. Within 1.5 seconds after acquisition, the Az and E errors read 0°; however, the antenna overshot and required 2.5 seconds to stabilize. The received signal power at acquisition measured -106 dBm at the directional coupler. Stable AUTO TRACK was maintained throughout the data run, with the antenna within $\pm 0.5^{\circ}$ of the target. During the initial portion of the run, the sum channel AGC showed a 0.5-Hz, ± 1 dB variation, but the tracking error remained at $0^{\circ} \pm 0.5^{\circ}$. No short-term deflections beyond the $\pm 0.5^{\circ}$ occurred during the run.

Flight 19, Data Run 1

Sector scan began at Point 3 on the standard racetrack pattern. Initial AUTO TRACK began 0.6 second after the start of the scan, but the lock was unstable, lasting only 4.8 seconds. The acquisition occurred at -113.5 dBm. Az and E tracking errors did

not reach 0° during this initial period of marginal signal. Sector scan continued until a stable AUTO TRACK occurred 19.5 seconds after initially originating scan. Az and E error signals stabilized at 0° error within 0.8 second after AUTO TRACK. The signal level at acquisition was -109 dBm at the A/RIA directional coupler. The UHF tracking receivers were configured with an FM demodulator and a 300-KHz IF bandwidth filter during Flight 19.

The tracking system remained in AUTO TRACK for the duration of the data run (10 minutes, 32.4 seconds). While the aircraft continued the turn between Points 3 and 4 on the pattern, the error signals remained at $0 \pm 0.5^\circ$. These deviations of $\pm 0.5^\circ$ were not oscillatory in nature, occurring over a 2- to 10-second period, primarily in the azimuth channel. As the aircraft flew the straight portion of the data run between Points 4 and 5, stability increased to $0 \pm 0.25^\circ$ in azimuth with essentially 0° error in elevation. The measured signal level during this period was -107 dBm at the directional coupler (approximately 1.1×10^{-14} watts/m^2). As the A/RIA flew around the racetrack between Points 5 and 6, at a turn rate of approximately 1°/second, stable tracking continued. Three 20-second periods were sampled during this period, and stability measured $0 + 0.25^\circ$. Small changes in azimuth were present as the aircraft approached Point 6 on the pattern, at a heading approaching 90° to the ground station.

Flight 19, Data Run 2

Sector scan was started at Point 3 on the pattern. The system went into stable AUTO TRACK 3.0 seconds after scan was begun. The azimuth and elevation errors decreased to 0° within 2.8 seconds of acquisition, with no discernible overshoot. The measured signal level at AUTO TRACK was -108 dBm at the A/RIA directional coupler.

Tracking on this run was very stable, with a maximum error of $\pm 0.5^\circ$. The error measured less than $\pm 0.25^\circ$ during all but a few seconds. The received signal increased to -106.5 dBm near the end of the run.

Flight 19, Data Run 3

The signal was acquired using Manual Scan, Automatic Acquisition, at Point 3 in the pattern. The measured signal power at acquisition was -108.5 dBm at the directional coupler. Tracking was very stable throughout the 13 minutes, 17 seconds of this data run. The elevation errors sampled over several one minute periods measured $\pm 0.25^\circ$. Azimuth stability was also $0^\circ \pm 0.25^\circ$.

Flight 20, Data Run 5

The operator manually slewed the antenna until a POSSIBLE TARGET came on. Sector scan was started, and the target was acquired within 0.5 second. Az and E tracking errors decreased to 0° within 0.2 second, and tracking stabilized after an overshoot of 0.8 second. The measured signal power at acquisition was -106 dBm at the directional coupler. Tracking was very stable throughout the run, with a measured

error of less than $\pm 0.5^{\circ}$ in azimuth and elevation. The signal level increased to -100 dBm at the end of the run.

Conclusion

It is concluded that the UHF tracking system requires an average of less than 2 seconds to stabilize after signal acquisition, using sector scan. Results indicate that the UHF system will track a nondynamic signal to a stability of $\pm 0.5^{\circ}$. It appears that tracking accuracy was excellent throughout the runs analyzed.

3.4.2.7 UHF System Performance —— Test 2

Acquire and track the C-121 at UHF.

Specification/Goal

Evaluate tracking performance at UHF.

Conditions

The A/RIA flew the pattern described in Section 3.1.3 (Flight Patterns) against the C-121. The A/RIA UHF system was configured for Unified S-Band, with a 1000-Hz tracking phase-lock loop. Tracking frequency was 2287.5 MHz.

Test Results

Data Run 1 through 4 on Flights 29 and 30 were evaluated for UHF tracking performance. The results are shown in Table IX. Overall tracking stability was excellent, with long-term drifts of less than $\pm 0.5^{\circ}$.

On Data Run 3 of Flight 30, the antenna drove off target four times while on AUTO TRACK. Investigation showed that HF transmitter 2, patched to the trailing wire antenna, was keyed just prior to the antenna excursion. This problem will be covered under the RFI section of this report.

3.4.2.8 UHF System Performance —— Test 3

Acquisition on a UHF sidelobe.

Goal

Determine the position and relative power of the UHF sidelobes.

Conditions

The A/RIA flew a normal racetrack pattern against the ground station for these tests. The UHF system was configured for Unified S-Band, with the PM demodulator set for

TABLE IX

UHF Tracking Stability, C-121 Signal Source

Flight Number	Run Number	Measured Signal Level at ACQ at Directional Coupler (0 dBm)	Track Stability (Overall)	Length of Run	Measured Signal at End of Run at Directional Coupler (-dBm)	Remarks
29	1	-114	±0.5° or better	10' 0"	-94	30 second time slice at ACQ + 32 seconds showed no discernible drift on LHC or RHC. Stable tracking throughout.
29	2	-120	±0.5° or better	15' 05"	-95	Stable tracking to near end of run. During intentional loss of signal, system in RATE MEMORY, E error signals drifted ±0.5°, cyclic, at 1.5-Hz rate.
29	3	-117 to -124	±0.25°	21' 40"	-102	10-second time slice sampled at ACQ. With signal of approximately -120 dBm, AZ and E errors showed stability within ±1.0°. Tracked to 110° off of aircraft heading.
29	4	-120	±0.5°	6' 35"	-119	10-second time slice sampled at ACQ. AZ and E stability ±1.0° (-120 dBm). Break lock tests performed during run. Stability apparently not affected by signal reduction. Remained ±0.5° at marginal signal levels.
30	1	-102	±0.25°	4' 26"	-80	20-second sample at ACQ showed stability at ±0.25°.
30	2	-110 to -112	±0.5°	12' 41"	-107	10-second sample at ACQ showed stability at ±0.5°. A second sample taken in center of run revealed stability at ±0.25°.
30	3	-110 to -112	±0.5°	14' 08"	-70	10-second sample at ACQ showed stability at ±0.5°. At ACQ plus 8 minutes, stability was ±0.25° Four times near end of run, antenna was driven off target (coincident with keying of HF transmitter patched to trailing wire antenna).
30	4	-112 to -121	±0.5°	19' 06"	-99	Intermittent initial ACQ because of low and fading signal. At ACQ plus 5 minutes, sample showed stability at ±0.5° (-111 dBm). A second sample showed ±0.25° stability.

a 1000-Hz tracking loop bandwidth. Two distinct tests were run, namely:

a. On Flight 16, acquisition on the first right and left sidelobes was accomplished, and the signal attenuated at the ground station to break lock on the sidelobe. A preliminary data run was flown to establish the acquisition/break lock level on the main lobe.

b. On Flight 24, acquisition was on the main lobe in a favorable signal environment. The antenna operator then offset the antenna by 5^o, 10^o, and 20^o Az right, Az left, up and down, and attempted to acquire at 10^o and 20^o offset points. The total duration of the test was approximately 5 minutes.

Test Results

Lock-Up on the First Sidelobe

This test was run on Flight 16, Data Runs 4 and 5. The preliminary run established acquisition and break lock on the main lobe at -115.9 dBm and -119.9 dBm, respectively, at the directional coupler. These are approximate values only, since the sidelobe acquisitions were made on a different data run than the main lobe acquisition. The system locked on a magnetic heading of 24^o.

The right sidelobe was acquired at a magnetic heading of 14^o. The sidelobe was acquired at -94.9 dBm, and broke lock at -97.9 dBm. Test results show that the right sidelobe position was positioned 10^o from the main lobe, and its power was 22 dB down from the main lobe.

The left sidelobe was acquired at a magnetic heading of 34^o. The system locked up at a power of -101.9 dBm and broke lock at -97.9 dBm. The results of this test positioned the left sidelobe 10^o from the main lobe, with a power 18 dB down from the main lobe. These positions are not necessarily those where the sum channel lobe is located. This is evident from the results of the sidelobe structure test presented later in this section. The test results are summarized in Table X.

TABLE X

UHF Sidelobe Measurements

	Magnetic Heading	Power at Break Lock (-dBm at D. C.)	Position of Lobe	Relative Power of Lobe (dB)
Main Lobe	24^o	-119.9	0^o	0
First Right Sidelobe	14^o	- 97.9	-10^o	-22
First Left Sidelobe	34^o	-101.9	$+10^o$	-18

Rough Cut of Right, Left, Up and Down Sidelobe Structure

On Flight 24, Data Run 6, a rough cut of the sidelobe structure was accomplished by first acquiring on the main lobe to establish a positional and signal power reference. The antenna was then offset by 5^o, 10^o, and 20^o right, left, up and down. Acquisition was attempted at 10^o and 20^o in each direction. To insure test accuracy, the antenna was returned to the target heading and the target reacquired after each excursion.

The test results are shown in Figure 56. Analysis of the data (Plot a) shows that the first attempted acquisition was at 20^o left. The system locked at 16^o as indicated, although the lack of a distinct lobe (error channel null) resulted in the antenna requiring 18 seconds to reach the position and signal level shown. The azimuth and elevation error signals were used to determine when and where the stable lock was achieved.

After reacquiring on the main lobe, the antenna was offset 10^o right and acquisition attempted (Plot b). The system locked at 9^o right in 4.55 seconds. The antenna actually reached 9^o right in 0.55 second, but overshot 0.3^o and took 4 seconds to reach a stable null at 9^o. No acquisition was attempted at 20^o right.

After reacquiring on the main lobe, the antenna was offset to 11^o up and acquisition attempted (Plot c). A stable lock was established at 9^o up. A second acquisition was attempted at 20^o up, and a stable lock established at 19^o up.

The antenna was positioned 12^o below the target and AUTO ACQUIRE depressed (Plot d). The antenna required 6 seconds to stabilize (within $\pm 0.5^o$) at 16^o down. This is apparently the second sidelobe. No further attempt was made to lockup on the first sidelobe. The lack of distinct sum channel lobe structure may be the result of high man-made noise.

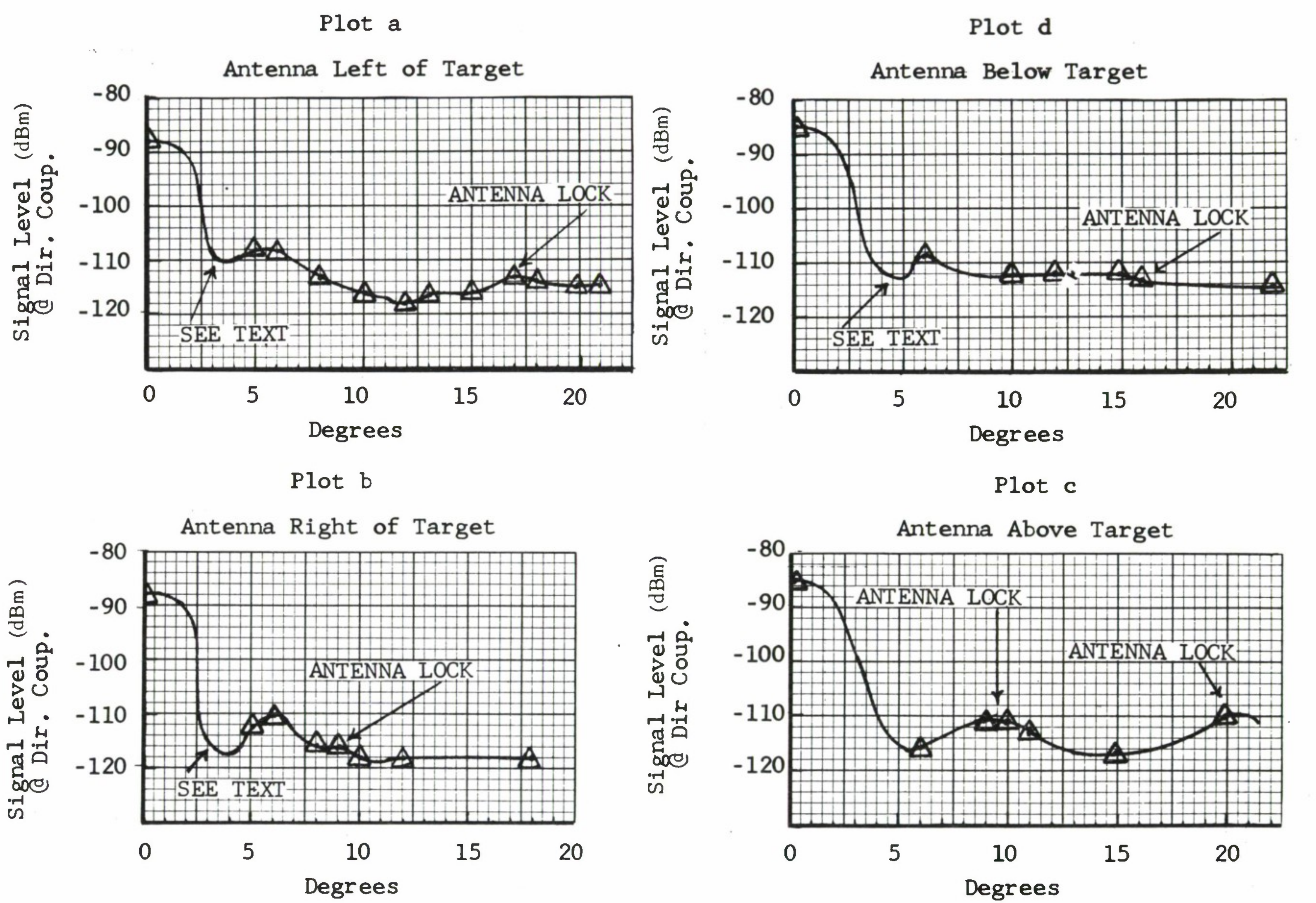
The structure of the pattern between the small triangles on Figure 56 is accurate regarding signal strength but not necessary regarding the position, in degrees, where the signal is plotted. This condition resulted from the speed at which the antenna operator slewed the antenna versus the one-frame-per-second speed of the photo recorder used to read antenna position. The triangles on the plots indicate where the antenna position was accurately read.

3.4.2.9 UHF System Performance —— Test 4

Determine the acquisition threshold of a modulated Unified S-Band signal, with a 3.3-MHz IF bandwidth (data) and a 1000-Hz tracking loop bandwidth.

Specification/Goal

Acquire and track a signal of -119 dBm at the directional coupler.



Indicates Points Where Both Antenna Position and Signal Power Could Be Correllated Accurately

FIGURE 56. UHF SIDELOBE STRUCTURE

Conditions

Unified S-Band acquisition threshold tests were performed with the A/RIA flying a standard racetrack pattern against the ground station and the NASA C-121. Acquisition is defined as when the PM demodulator PHASE LOCKED lamp comes on. The phase-lock-loop break-lock threshold is 2 dB to 3 dB below (less power) the acquisition threshold. These tests were performed by the following procedure.

a. A voice link was established between the A/RIA and the ground station or C-121 on VHF or UHF.

b. A signal several dB above the expected threshold was acquired using sector scan/automatic acquisition.

c. Once stable AUTO TRACK on UHF was established, the signal was attenuated at the source (ground station or C-121) in 1-dB steps until the AUTO TRACK light went out.

d. The signal was immediately increased until reacquisition of AUTO TRACK.

The data used to determine the acquisition and break lock points were reduced from instrumentation records. The GMT of AUTO TRACK (ON or OFF) was taken from event recorder records and the signal strength read from the oscillograph records at the same GMT.

The theoretical acquisition level is determined as follows:

Φ_{kt} (Noise Spectral Density, $T_{sys} = 1069^{o}K$)	-168. 3 dBm/Hz
Carrier Modulation Loss	+ 4. 1 dB
Tracking Loop Predetection Noise Bandwidth (2000 Hz)	+ 33. 0 dB
Predetection SNR Required for AUTO TRACK	+ 6. 0 dB
Automatic Receiver Acquisition	+ 5. 0 dB
Theoretical Acquisition Threshold at Antenna Load	-120. 2 dBm
Theoretical Acquisition Threshold at the Directional Coupler	-122. 2 dBm

The acquisition threshold tests were performed with the carrier being modulated by both subcarriers. The data subcarrier was modulated with 51. 2-KBPS data.

Test Results

Acquisition threshold tests were performed on Flights 21, 29, and 20. The results are shown in Table XI.

TABLE XI

UHF Acquisition Thresholds (USB Format)

Flight #	Run #	Measurement #	Measured Acquisition Level at the Directional Coupler (-dBm)	Measured Break Lock Level at Directional Coupler (-dBm)
21	1	1		-121
		2	-119	-121
		3	-119	-121
		4	-119	-121
		5	-119.5	-121
		6	-119	-120
		7	-119	-121
		8	-119	-121
29	4	1		
		2	-122.5	-123.5
		3	-122	-123
30	4	1		-120
		2	-118	-117.5
		3	-115.5	-120
		4	-118.5	

The median value for acquisition is -119 dBm and the mean -119 dBm. These test results indicate that the A/RIA can acquire and track a signal of 1.1×10^{-15} watts/m^2 if configured as outlined in this test. These results are accurate to ± 2 dB, placing the acquisition range at 1.8×10^{-15} watts/m^2 to 7.1×10^{-16} watts/m^2.

The difference between the theoretical acquisition threshold (-122.2 dBm) and the measured threshold (-119 dBm) may be attributed to either an increased modulation loss or an increased system noise temperature.

3.4.2.10 UHF System Performance —— Test 5

Determine the acquisition threshold of a modulated UHF (S-Band) carrier, PCM/FM, with a 300-KHz IF bandwidth filter.

Specification/Goal

Acquire and track a signal of -113.5 dBm at the directional coupler.

Conditions

UHF (S-Band) acquisition threshold tests, using an FM demodulator, were performed against the ground station. The receivers were configured with a 300-KHz IF bandwidth filter. The tests were accomplished by the procedure described under Test 4, Paragraph 3.4.2.9. Acquisition was reduced from instrumentation records by correlating the GMT of AUTO TRACK with the signal strength read at that time.

Because of the low man-made noise at UHF, the COR was set to initiate AUTO TRACK with 2-dB SNR in the IF, rather than the 6 dB used for VHF. The theoretical acquisition level is determined as follows:

Φ kt (Noise Spectral Density, $T_{sys} = 1069^{o}K$)	-168.3 dBm/Hz
Predetection Noise Bandwidth (300-KHz IF)	54.8 dB
Predetection SNR required for AUTO TRACK	2.0 dB
Theoretical Acquisition Threshold at Antenna Load	-111.5 dBm
Theoretical Acquisition Threshold at the Directional Coupler	-113.5 dBm

The acquisition threshold tests were performed with the carrier modulated PCM/FM, with a deviation of $\pm$35 KHz. No modulation loss is applicable for this test, since all power remains within the receiver bandwidth.

Test Results

This test was performed on Flight 19. The results are shown in Table XII.

TABLE XII

UHF Acquisition Thresholds (PCM/FM Format)

Measurement Number	Measured Acquisition Level at the Directional Coupler (-dBm)	Measured Break Lock Level at Directional Coupler (-dBm)
1	-114	-115
2	-109	-115
3	-114	-115
4	-114	-115
5	-114	-116
6	-115	-115
7	-115	

The median value for acquisition is -114 dBm and the mean -113.5 dBm. These test results indicate that the A/RIA can acquire and track a signal of 4.0 X 10^{-15} watts/m^2, if configured as outlined in this test. These results are accurate to ± 2 dB, placing the acquisition range at 6.3 X 10^{-15} watts/m^2 to 2.5 X 10^{-15} watts/m^2. Use of a 2-dB predetection SNR did not result in any false locks.

3.4.2.11 UHF System Performance —— Test 6

Determine the acquisition threshold of a modulated UHF (L-Band) carrier, PCM/FM, with a 300-KHz IF bandwidth filter.

Specification/Goal

Acquire and track a signal of -108.8 dBm at the directional coupler.

Conditions

UHF (L-Band) acquisition threshold tests, using an FM demodulator, were performed against the ground station. The receivers were configured with a 300-KHz IF bandwidth filter. The tests were accomplished by the procedure described under Test 4, Paragraph 3.4.2.9. Acquisition was reduced from instrumentation records by correlating the GMT of AUTO TRACK with the signal strength read at that time.

Because of the low man-made noise at UHF, the COR was set to initiate AUTO TRACK with 2-dB SNR in the IF, rather than the 6 dB used for VHF. The theoretical acquisition level is determined as follows:

Φ_{kt} (Noise Spectral Density, Ref. Note 32)	-163.6 dBm/Hz
Predetection noise bandwidth (300 KHz IF)	54.8 dB
Predetection SNR required for AUTO TRACK	2.0 dB
Theoretical Acquisition Threshold at Antenna Load	-106.8 dBm
Theoretical Acquisition Threshold at the Directional Coupler	-108.8 dBm

The acquisition threshold tests were performed with the carrier modulated PCM/FM, with a deviation of ± 125 KHz. No modulation loss is applicable for this test, since all power remains within the receiver bandwidth.

Test Results

This test was performed on Flight 31. Test results are listed in Table XIII.

TABLE XIII

UHF Acquisition Thresholds (L-Band)

Measurement Number	Measured Acquisition Level at the Directional Coupler (-dBm)	Measured Break Lock Level at Directional Coupler (-dBm)
1	-109	-109.5
2	-108.5	-109.5
3	-109	-109.5
4	-109	-109.5
5	-109	-109.5
6	-109	-109.5

The median value for acquisition is -109 dBm and the mean -108.9 dBm. These test results indicate that the A/RIA can acquire and track a signal of 2.0×10^{-14} watts/m^2, if configured as outlined in this test. These results are accurate to ± 2 dB, placing the acquisition range at 1.3×10^{-14} watts/m^2 to 3.5×10^{-14} watts/m^2.

3.4.2.12 UHF System Performance —— Test 7

Acquire and track at UHF (L-Band).

Specification/Goal

Demonstrate the capability of A/RIA to acquire and track a target at L-Band.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. The system was configured with an FM demodulator and a 300-KHz IF bandwidth filter. The tracking frequency was 1501.0 MHz.

Test Results

The A/RIA tracked on L-Band during Data Run 1 through 4 on Flight 31. The results are given in Table XIV.

Tracking stability was very good during all four data runs. The stability was actually better than the resolution of the measurement most of the time ($\pm 0.25^{\circ}$). The system tracked from Point 3 on the pattern to the azimuth limit at Point 6.

TABLE XIV

UHF Tracking Stability, L-Band Source

Run Number	Measured Signal Level at ACQ (-dBm) at D. C.	ACQ On	Track On	Track Stability (overall)	Length of Run	Measured Signal Level at End of Run (-dBm) at D. C.
1	-98.5	RHC	RHC	$\pm 0.5^{\circ}$ or better	9'40"	-98.5
2	-108.0	RHC	RHC	$\pm 0.5^{\circ}$ or better	9'17"	-102.5
3	-103.5	RHC	RHC	$\pm 0.5^{\circ}$ or better	7'23"	-99.5
4	-102.0	RHC	RHC	$\pm 0.5^{\circ}$ or better	8'54"	-105.5

3.4.2.13 UHF System Performance —— Test 8

Evaluate rate memory operation, UHF and VHF.

Goal/Specification

Determine the amount of antenna pointing error accumulated during short periods of loss of signal.

Conditions

Rate memory tests were performed with the A/RIA ground station, the NASA C-121, and the ballistic missile. Ground station and C-121 tests were implemented by the aircraft making a constant-rate turn away from the target for a period of more than 10 seconds (tracking system in AUTO TRACK). The signal was then turned off at the source for a period up to 10 seconds, with the system in RATE MEMORY. The signal was turned on, and the accumulated error measured. Rate memory also occurred for 2.5 seconds during the ballistic missile mission.

Test Results

Rate memory tests were performed on Flights 13, 25, 29, 30, and 31. Rate memory also occurred on Flight 27. The test results are presented in Table XV.

TABLE XV

Rate Memory Test Results
(Test No. 8)

Flight No.	Track Mode	Rate Memory Interval (Seconds)	Rate of Change of A/C Heading at Loss of AUTO TRACK Degrees/Second	Rate of Change of Position at Loss of of AUTO TRACK Degrees/Second		Accumulated Error at Continuation of AUTO TRACK (Degrees)	
				E	Az	E	Az
25	UHF (USB)	1. 2	0. 6	0	0	1	1
	UHF (USB	2. 5	0. 6	0	0	1	1
29	UHF (USB	3. 4	0. 3	0	0	1	0
30	UHF (USB)	7. 5	0. 66	0	0	1	2
	UHF (USB)	7. 7	0	0	0	1	1
	UHF (USB)	9. 5	0	0	0	1	0
	UHF (USB)	3. 5	1. 9	0	0	1	0
31	UHF (L-Band)	7. 0	0. 9	0	0	0	0
	UHF (L-Band)	7. 6	0. 8	0	0	0	2
	UHF (L-Band)	8. 5	0. 66	0	0	1	0
	UHF (L-Band)	9. 8	0. 5	0	0	1	1
	UHF (L-Band)	1. 3	0. 62	0	0	0	1
	UHF (L-Band)	9. 0	0. 5	0	0	1	1
	UHF (L-Band)	6. 2	2. 6	0	0	0	1
13	VHF	2. 0	0. 2	0	0	0	1
27	VHF	2. 5	0	2. 8	1. 0	0	1*

*This is assumed since the missile may have changed the rate of change during the rate memory interval.

The rate memory test results are as predicted. The maximum period that the system will remain in rate memory mode, before indicating a Loss of Signal (LOS), was measured to be between 9.0 and 9.6 seconds.

3.4.3 Functional Reliability/Operability

The VHF and UHF tracking systems demonstrated good reliability during the test program. A listing of inflight equipment failures is included in Table XVI.

The phasing problem is discussed in Section 3.4.4, Design/Operational Problems.

3.4.4 Design/Operational Problems

The two basic tracking problems experienced during Category II were receiver phasing (UHF and VHF) and slow response on VHF.

3.4.4.1 Problem —— Tracking Receiver Phasing

The receiver phasing problem compromised several data runs during the program. Analysis of instrumentation records showed that one or more tracking receivers were improperly phased on most data runs.

Recommended Solution

During the Category II Test Program, the test aircraft was equipped with a system for inflight adjustment of the tracking receiver phasing controls. Considerable difficulty was experienced in making phasing adjustment. It has been determined that this inflight phasing system (identified elsewhere in the program as ECP 21) was incorrectly implemented in the test aircraft; therefore, the entire Category II Flight Test Program was conducted without the assistance of any inflight phasing arrangements such as ECP 21. Phasing was accomplished by adjusting the receiver phasing in flight on the basis of experimentally tracking the ground station. This technique is very crude and test results indicate that it was not 100-percent effective. The result of such crude adjustments of the phasing control was in many cases a spiraling of the antenna toward the correct azimuth and elevation location. The crux of the problem resided in the fact that the techniques used throughout the Category II program for alignment on the collimation tower were inadequate. During the first week in April a party from the main Engineering Group in Towson spent 4 days in Tulsa developing and qualifying an experimental technique for adjusting receiver phasing on the collimation tower with the aircraft on the ground. Following this, a modification of ECP 21 was installed in Aircraft No. 330. The ECP 21 adjustment technique was checked against the collimation tower technique which had been developed and the performance appeared to be highly satisfactory. Both the collimation tower technique and ECP 21 readjustments in flight were experimentally checked and found satisfactory during the May 4 mission (Athena Tracking Mission); therefore, it is recommended that in flight phasing without benefit of ECP 21 be avoided in the future operation of the aircraft and

TABLE XVI

Tracking System Failure During Category II Tests

Flt. No.	Problem/Failure	Corrective Action
7	No Auto Acquisition signal from UHF/RHC receiver	None. Malfunction could not be verified on ground check.
8	No Auto Acquisition signal from UHF/RHC receiver	Replaced operational amplifier in tracking error demodulator (track receiver).
10	No lock signal from UHF/LHC track receiver	Replaced tracking error demodulator while in flight.
	System oscillating when tracking on UHF/RHC	Reduced ground station Power to -80 dBm at directional coupler. Tracking error demodulator dynamic range of approximately -60 dBm to -120 dBm was exceeded.
11	UHF/LHC track receiver would not lock	Replaced lock relay in tracking demodulator.
12	Antenna would not control properly immediately after power on. A change in Az caused a change in E, and vice versa	None. Problem corrected itself after warm up.
14	VHF/RHC would not lock	Repaired in-flight. Replaced RF head (low gain).
18	VHF/LHC AGC not in tracking combiner	Broken cable. Repaired cable.
27	Unstable VHF tracking	Receivers apparently not phased properly.
27	Pre and post mission cals differ by 6 dB. Cause was interference during pre-mission cal.	None.
29	VHF/LHC locks up 4^{o} to 5^{o} from other receivers.	VHF/LHC improperly phased.

that preflight phasing of the receivers be carefully conducted with the collimation tower and the procedures outlined in the instruction manual.

The AGERD covering the collimation tower was approved but not ordered as operational AGE. Makeshift collimation tower equipment may be the source of substantial field problems similar to those described above and should be used with extreme caution.

3.4.4.2 Problem —— Slow Response During VHF Tracking

Analysis of tracking data has shown that the response of the VHF channel was substantially slower than the UHF channel response.

Recommended Solution

For the same number of degrees of offset, the antenna pulled into the target and stabilized five to ten times faster on UHF. Investigation of this problem revealed that the L-BAND/VHF switch in the tracking combiner had been in the L-Band position during all VHF tracking tests on the primary test aircraft (A/RIA 372). In the L-BAND position, 18-dB attenuation is inserted into the Az and E error voltage lines, whereas only 3-dB attenuation is inserted in the VHF position. This switch was designed into the tracking combiner to permit simultaneous use of L-Band and S-Band tracking. The design concept was to have substantially the same servo response regardless of the tracking frequency. Tests run at Bendix Radio showed that the VHF system could be set up to respond as quickly as UHF, once the attenuation was cut to 3 dB and the receiver error voltage outputs readjusted.

3.4.4.3 Problem —— HF Transmission Effect - UHF/VHF Antenna Servo

Several times late in the program the antenna drove to limits while tracking. This occurred on Flights 29 and 30. Analysis of instrumentation records showed that the antenna excursion occurred (UHF and VHF tracking) when the HF operator keyed the transmitter patched to the trailing wire antenna. Later tests on Flight 29 of A/RIA 327 isolated the problem to the trailing wire antenna at frequencies above approximately 9 MHz. This problem is covered under the RFI section of this report.

3.5 RECEIVE AND RECORD TELEMETRY DATA

3.5.1 Receive and Record Telemetry Data on VHF

3.5.1.1 VHF Test Result Summary

The A/RIA has successfully demonstrated the ability to receive and record VHF telemetry data. Telemetry data schemes included PCM/FM and FM/FM, with bit rates from 1.6 KBPS to 72 KBPS. Data were taken through 300-KHz to 1.5-MHz IF bandwidth filters. Data were recorded in predetection uncombined, predetection combined, and post-detection modes. Test results for 51.2 KBPS indicate a data SNR of

7 dB to 35.5 dB at received power levels of -106 dBm to -79 dBm, respectively, referenced to the antenna load.

Recorded telemetry data were evaluated by analyzing SNR versus received signal power. Although a coded PCM pulse train was recorded on two flights, no bit error count has been performed on the tapes.

VHF telemetry system reliability was satisfactory during the Flight Test Program.

3.5.1.2 VHF Tests Performed

Test 1 Receive and record VHF telemetry data, PCM/FM, 51.2-KBPS, ±125-KHz deviation, from the ground station.

Test 2 Receive and record VHF telemetry data, PCM/FM, 1.6-KBPS, ±125-KHz deviation, from the ground station.

Test 3 Receive and record VHF telemetry data, PCM/FM, 72-KBPS, ±39-KHz deviation, from the ground station.

Test 4 Receive and record VHF telemetry data, FM/FM, ±125-KHz deviation, from the ground station.

Test 5 Derive a curve of output SNR versus input signal power from -80 dBm to system threshold for VHF PCM/FM data, 51.2-KBPS, ±125-KHz deviation.

Test 6 Receive and record VHF telemetry data, PCM/FM, 51.2-KBPS, ±125-KHz deviation from the NASA C-121.

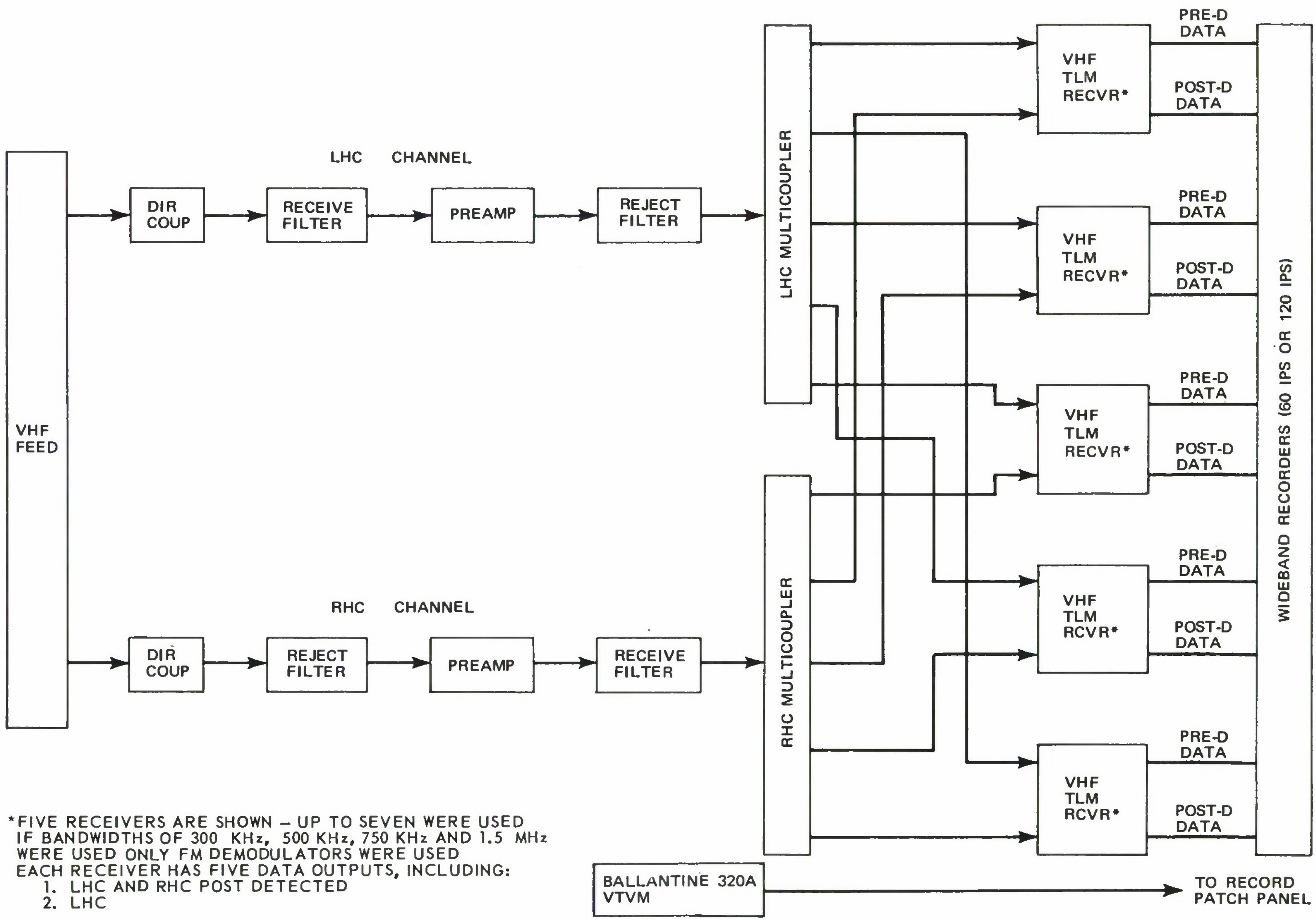
3.5.1.3 Test Environment

VHF telemetry data were received and recorded from the Tulsa ground station, the NASA C-121, the Gemini spacecraft, and the ballistic missile during Category II. Since no report is available on the data recorded during the Gemini or ballistic missile flights, this section includes only telemetry data taken from the ground station and the C-121. A discussion of these facilities, and the control of signals transmitted from them, is included in Sections 3.1.4 and 3.1.5, respectively.

3.5.1.4 Data Collection Technique

Signal plus noise-to-noise measurements of VHF telemetry data were taken during flight by the Record Operator with a Ballantine 320A VTVM, as shown in Figure 57. The modulation was turned off at intervals during the data run to provide the noise readings.

Signal plus noise-to-noise measurements were also taken from the magnetic tapes recorded during the data runs. Readings of both predetection and post detection were accomplished, using the configuration shown in Figure 58.



*FIVE RECEIVERS ARE SHOWN – UP TO SEVEN WERE USED IF BANDWIDTHS OF 300 KHz, 500 KHz, 750 KHz AND 1.5 MHz WERE USED ONLY FM DEMODULATORS WERE USED
EACH RECEIVER HAS FIVE DATA OUTPUTS, INCLUDING:
1. LHC AND RHC POST DETECTED
2. LHC

FIGURE 57. VHF DATA, RECORD SYSTEM CONFIGURATION

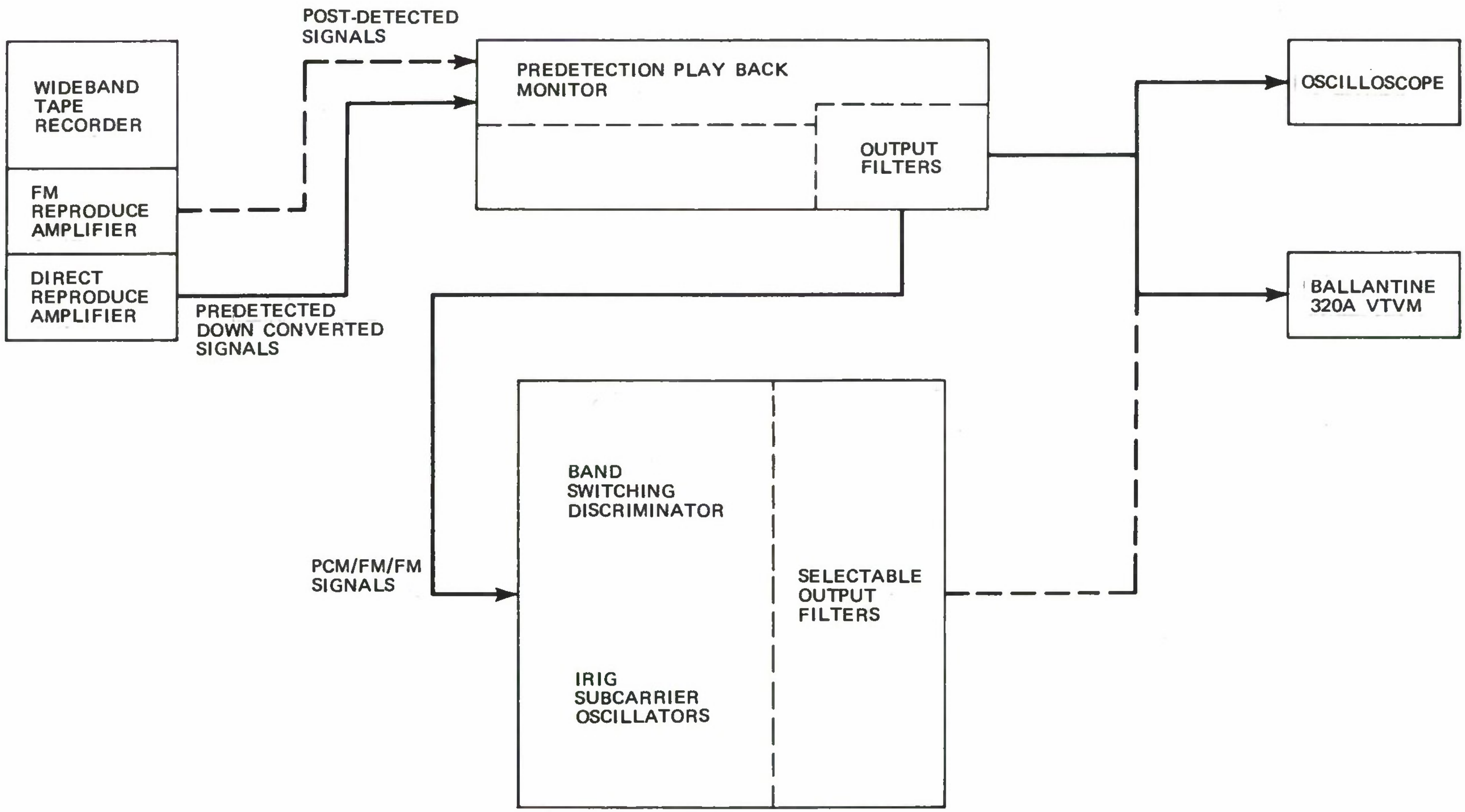


FIGURE 58. WIDEBAND MAGNETIC TAPE REDUCTION SET-UP

The signal levels shown under the Test Results section were measured from oscillograph records. Calibration of AGC to derive signal strength is discussed in Section 3.1.5.

3.5.1.5 System Configuration

The A/RIA PMEE configuration used during all VHF telemetry data tests is shown in Figure 57. The signals are received at the VHF antenna, amplified by the pre-amplifiers in the LHC and RHC channels and fed to the multicouplers. The multicoupler outputs are patched to the compatible receiver channels. The receiver predetected data outputs were patched to direct record modules and recorded on the wide-band records; post-detected signals were patched through FM record modules to the recorder.

3.5.1.6 VHF System Performance —— Test 1

Receive and record VHF telemetry data, PCM/FM, 51.2 KBPS, ±125-KHz deviation, from the ground station.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal power used.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data were received at 237.8 MHz, PCM/FM, 51.2 KBPS, with an FM carrier deviation of ±125 KHz. The received signal power at the A/RIA was between 5.4 X 10^{-13} watts/m^2 and 1.2 X 10^{-14} watts/m^2 (-90.5 dBm to -107 dBm at the A/RIA directional coupler).

Test Results

Test results using a 300-KHz IF bandwidth filter are shown in Table XVII. Measured signal plus noise-to-noise ratios in this table were taken from magnetic tape and operator readings. The computed SNR's at the measured signal power are shown in the last column of the table. The derivation of these values is included at the end of this section.

The results indicate that measured output signal-to-noise ratios are in general agreement with the computed values at received signal levels from -103 dBm to -107 dBm. This represents a SNR of 7.6 dB to 11.6 dB in the receiver IF. The measured values deviate by -3 dB to +4 dB, well within the established tolerance defined in NOTE 2 at the end of this section. Analysis of the results shows that the predetection combined SNR is better than either channel, by 2 dB to 3 dB, on Flight 22. On Flight 25, Runs 2 and 3, the combined output was equal to the uncombined. One explanation for the

TABLE XVII

VHF Data, SNR Versus Power Level (52 KBPS)

Data Source Flt No., Run No.	TLM Rcvr No.	Signal	Measured Signal Power at A/RIA Directional Coupler (dBm)	Measured S+N/N from Tape (dB)	Measured S+N/N from Operator's Log (dB)	Computed SNR (dB) NOTE 1
22, 6	4	CH 1, Pre-D	-105	14		14.9
		CH 2, Pre-D		15		14.9
		Pre-D Comb		18		
		CH 1, Post-D			15	14.9
		CH 2, Post-D		16	17	14.9
	4	CH 1, Pre-D	-106	13		13.4
		CH 2, Pre-D		14		13.4
		Pre-D Comb		16		
		CH 1, Post-D			14	13.4
		CH 2, Post-D		15.5	14.5	13.4
	4	CH 1, Pre-D	-107	12		11.9
		CH 2, Pre-D		11		11.9
		Pre-D Comb		13		
		CH 1, Post-D			13	11.9
		CH 2, Post-D		16	13	11.9
25, 2	4	CH 1, Pre-D	-103	19		17.1
		CH 2, Pre-D	-104	19		16.1
		Pre-D Comb		19		
	2	CH 1, Pre-D	-103	19		17.1
		CH 2, Pre-D	-104	19		16.1
		Pre-D Comb		19		
25, 3	4	CH 1, Pre-D	-103	19		17.1
		CH 2, Pre-D	-104	19		16.1
		Pre-D Comb		19		
	2	CH 1, Pre-D	-103	19		17.1
		CH 2, Pre-D	-104	19		16.1
		Pre-D Comb		19		
25, 4	4	CH 1, Pre-D	-104	19.5		16.1
		CH 2, Pre-D	-105	17.5		14.9
		Pre-D Comb		21.0		
	2	CH 1, Pre-D	-104	19.5		16.1
		CH 2, Pre-D	-105	13.0		14.9
		Pre-D Comb		17.0		

NOTE:

A. A 300-KHz IF bandwidth filter was used for all tests. Post-detection signals were recorded through a 100-KHz video filter.
B. A 100-KHz video bandwidth filter was used when reading all tapes.
C. Post-detection operator readings were taken through a 100-KHz video filter.

lack of improvement is high man-made noise, which combines coherently the same as signal combining. The signal-to-noise ratio improvement derived from a combiner is dependent upon the noise being incoherent.

The output of receiver 2 on Flight 24, Data Run 4, is inconsistent with other results of this test. Channel 2 had an apparent malfunction, since its output SNR is 4.5 dB less than the same signal recorded on Channel 2 of Receiver 2. This malfunction also affected combiner operation since the combined SNR is 2.5 dB less than the Channel 1 output.

3.5.1.7 VHF System Performance —— Test 2

Receive and record VHF telemetry data, PCM/FM, 1.6 KBPS, ±125-KHz deviation, from the ground station.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal power.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data were received at 237.8 MHz, PCM/FM, 1.6 KBPS, with an FM carrier deviation of ±125 KHz. The received signal power at the A/RIA was 3.8×10^{-14} watts/m^2 (-102 dBm at the directional coupler). A 300-KHz IF bandwidth filter was used for all tests. All data were measured through a 3-KHz video bandwidth filter.

Test Results

The data for these test results were taken from Flights 21 and 24; the measured S+N/N ratios were reduced from magnetic tapes. Although the tolerance discussed in NOTE 2 at the end of this section is applicable for this test, the predetection SNR was high enough to give maximum output SNR without correcting for this factor. The maximum SNR is limited by the wideband recorder response. It is evident that the very steep FM improvement curve resulting from the high modulation index will cause the system to produce adequate data at relatively low predetection signal-to-noise levels (see Table XVIII).

3.5.1.8 VHF System Performance —— Test 3

Receive and record VHF telemetry data, PCM/FM, 72 KBPS, ±39 KHz deviation, from the ground station.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal power.

TABLE XVIII

VHF Data SNR Versus Power Level (1.6 KBPS)

Data Source Flt No. Run No.	TLM Rcvr No.	Signal	Measured Signal Power at A/RIA Directional Coupler (dBm)	Measured S+N/N from Tape (dB)	Computed SNR * (NOTE 2) (dB)
21, 4	4	CH 1, Pre-D	-101	44	67.6
		CH 2, Pre-D	-101	44	67.6
		Pre-D Comb		47	67.6
		CH 1, Post-D		39	
24, 5	4	CH 1, Pre-D	-102	43	66.6
		CH 2, Pre-D	-102	47	66.6
		Pre-D Comb		47	66.6
	2	CH 1, Pre-D	-102	46	66.6
		CH 2, Pre-D	-102	47	66.6
		Pre-D Comb		45	66.6
24, 6	4	CH 1, Pre-D	-102	45.5	66.6
		CH 2, Pre-D	-102	44.5	66.6
		Pre-D Comb		45.5	66.6
	2	CH 1, Pre-D	-102	45.5	66.6
		CH 2, Pre-D	-102	46.5	66.6
		Pre-D Comb		46.5	66.6

* These computed values are beyond the capability of the tape recorder. The manufacturer's specification gives a 19-dB SNR for the recorder at 60 ips in direct record mode. The 1.6-KBPS data were read through a 3-kc video filter, giving a maximum data SNR of:

$$\text{SNR} = 19 + 10 \log \frac{1.5 \times 10^{6}}{6.0 \times 10^{3}}$$

$$\text{SNR} = 4^{3} \text{ dB maximum}$$

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data was received at 232.9 MHz, PCM/FM, 72 KBPS, with an FM carrier deviation of ±39 KHz. The received signal power at the A/RIA was 5.4 X 10^{-13} watts/m^2 (-90.5 dBm at the directional coupler). A 300 KHz IF bandwidth and a 100 KHz video bandwidth were used for this test.

Test Results

This test was run on Flight 19, Data Run 7. Telemetry data recorded on the wideband recorder during this flight were defective because of operator error. The readings listed in Table XIX were taken by the Record Operator from the Record Patch Panel with a Ballantine 320A VTVM. Comparison of measured S+N/N ratios to computed SNR, using the established tolerance (NOTE 2 at the end of this section), indicates that the test results are as predicted. The operator readings are post-detected only, so combiner performance cannot be evaluated for this test.

The modulation scheme tested is one used by the Apollo Saturn IV-B stage. The combination of a relatively high data rate (72 KBPS), and a small carrier deviation (±39 KHz) results in negative FM improvement (see NOTE 3 at the end of this section).

3.5.1.9 VHF System Performance —— Test 4

Receive and record VHF telemetry data, FM/FM, ±125-KHz and ±250-KHz deviation, from the ground station.

Specification/Goal

Qualitatively evaluate the capability of the A/RIA to receive and record FM/FM telemetry data in preparation for support of a DOD ballistic missile mission.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data were received at 237.8 MHz, FM/FM, with a ±125-KHz carrier deviation on Run 2 and a 250-KHz carrier deviation on Run 3. The data were 20-Hz square wave FM modulated on IRIG subcarriers 5 through 18. The data were received by seven VHF telemetry receivers simultaneously, having IF bandwidth filters of 300 KHz

TABLE XIX
VHF Data, SNR Versus Power Level (72 KBPS)

Measure-ment Number	Signal	TLM Rcvr #	Measured Signal Level at A/RIA Direct Coupler (dBm)		Measured S+N/N from Operator's Log (dB)		Computed S+N/N (NOTE 3)(dB)	
			CH #1	CH #2	CH #1	CH #2	CH #1	CH #2
1	Post-D	4	-89.5	-89.5	23	23	20.4	20.4
2	Post-D	4	-89.5	-89.5	23	23	20.4	20.4
3	Post-D	4	-89.5	-89.5	23	23	20.4	20.4
4	Post-D	4	-88.5	-88.5	22	23	21.4	21.4
5	Post-D	4	-88	-90	23	22	21.9	19.9
6	Post-D	4	-88	-90	22	22	21.9	19.9
7	Post-D	4	-88	-90	23	22	21.9	19.9
8	Post-D	4	-87	-90	24	23	22.9	19.9
9	Post-D	4	-85.5	-89	24	23	24.4	20.9
10	Post-D	4	-85.5	-89	24	23	24.4	20.9
11	Post-D	4	-85.5	-89	24	23	24.4	20.9
12	Post-D	4	-85.5	-87.5	24	23	24.4	22.4
13	Post-D	4	-86	-88	24	23	23.9	21.9
14	Post-D	4	-86.5	-88	23	22	23.4	21.9
15	Post-D	4	-87.5	-89	23	22	22.4	20.9
16	Post-D	4	-88	-89	22	22	21.9	20.8
17	Post-D	4	-89	-89.5	22	22	20.9	20.4
18	Post-D	4	-91.5	-91	21	20	18.4	18.9

(two receivers), 500 KHz (three receivers), and 1.5 MHz (two receivers). The telemetry data were read through the video filters listed below:

IRIG Channel	Video Filter (Hz)	IRIG Channel	Video Filter (Hz)
5	20	12	160
6	25	13	220
7	35	14	330
8	45	15	450
9	59	16	600
10	81	17	790
11	110	18	1050

The three predetection outputs from each receiver were recorded on the wideband recorders; two recorders were used. This test was run on Flight 23, Data Runs 2 and 3.

Test Results

This test was performed on Flight 23, Data Runs 2 and 3. The results are shown in Table XX. The telemetry data from all subcarriers were checked on an oscilloscope and found to be good; however, S+N/N ratios were read only from the lowest (Channel 5) and highest (Channel 18) frequency subcarriers. The tables list the carrier noise level (N_c), the subcarrier noise level (N_{sc}), the signal plus subcarrier noise level ($S+N_{sc}$), as well as the data SNR $\left(\frac{S+N_{sc}}{N_{sc}}\right)$. Data signal-to-noise ratios of 17 dB to 30 dB were measured at levels equivalent to 8 dB to 10 dB SNR in the receiver IF.

No quantitative evaluation of test results is possible because of the relatively uncontrolled manner of generating the signals from the ground station. It was not possible to measure the carrier deviation of each subcarrier; also, a 20-Hz square wave was used to modulate all channels, regardless of individual channel frequency response. A variation in the modulation index of the 20-Hz square wave on each subcarrier is present. Since the pre-emphasis used in the ground station is also unknown, an accurate performance prediction is not possible.

3.5.1.10 VHF System Performance —— Test 5

Derive a curve of output SNR versus input signal power from -80 dBm to system threshold for VHF PCM/FM data, 51.2 KBPS, $\pm$125 deviation.

Goal

Compare the measured curve to the computed curve.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data was received at 237.8 MHz, PCM/FM, 51.2 KBPS, with an FM carrier deviation

TABLE XX

VHF Data, SNR Versus Power Level (FM/FM Format)

Wideband Recorder Number	Recorder Track	TLM Receiver	Receiver Channel	IFBW Filter	Measured Signal Level Directional Coupler (dbm)	IR IG SCO #5				IR IG SCO #18		
						N_c	N_{sc}	$S+N_{sc}$	SNR	N_{sc}	$S+N_{sc}$	SNR
2	4	3	1	300 kc	-106	-33	-18	+1	19	-27	+2	29
	5	3	2		-106	-33	-23	+1	24	-28	+2	30
	6	3	Comb			-33	-23	+1	24	22	+2	24
2	10	7	1	300 kc		Output noise only. Receiver inadvertently operated in APC instead of AFC mode.						
	11	7	2									
	12	7	Comb									
1	1	2	1	500 kc	-106	-34	-25	0	25	-27	+1	28
	2	2	2		-106	-34	-25	0	25	-26	+1	27
	3	2	Comb			-34	-28	0	28	-28	+1	29
1	4	4	1	500 kc	-106	-34	-24	0	24	-26	+1	27
	5	4	2		-106	-34	-25	0	25	-26	+1	27
	6	4	Comb			-34	-26	0	26	-27	+1	28
2	1	1	1	500 kc	-106	-33	-18	+1	19	-26	+2	28
	2	1	2		-106	-33	-20	+1	21	-27	+2	29
	3	1	Comb		-106	-33	-20	+1	21	-28	+2	30
1	7	6	1	1.5 mc	-105	-34	-26	+1.8	27.8	-22	+0.8	22.8
	10	6	2		-105	-34	-27	+1.8	28.8	-22	+0.8	22.8
	11	6	Comb			-34	-28	+1.8	29.8	-25	+0.8	25.8
2	7	5	1	1.5 mc	-104.5	-33	-18	+1	19	-26	+2	28
	8	5	2		-104	-33	-16	+1	17	-26	+2	28
	9	5	Comb			-33	-22	+1	23	-28	+2	30

TABLE XX (Continued)

Wideband Recorder Number	Recorder Track	TLM Receiver	Receiver Channel	IFBW Filter	Measured Signal Level Directional Coupler (dbm)	SNR Measurements (db)						
						IR IG SCO #5 (1.3 KC)				IR IG SCO #18 (70 KC)		
						N_c	N_{sc}	$S+N_{sc}$	SNR	N_{sc}	$S+N_{sc}$	SNR
2	4	3	1	300 kc	-106	-33	-18	+1	19	-27	+2	29
	5	3	2		-106	-33	-23	+1	24	-28	+2	30
	6	3	Comb			-33	-23	+1	24	-22	+2	24
2	10	7	1	300 kc		Output noise only. Receiver inadvertently operated in APC instead of AFC mode.						
	11	7	2									
	12	7	Comb									
1	1	2	1	500 kc	-106	-34	-27	+1.8	28.8	-22	+1.0	23
	2	2	2		-106	-34	-27	+1.8	28.8	-25	+0.8	25.8
	3	2	Comb			-34	-28	+1.8	29.8	-28	+0.8	28.8
1	4	4	1	500 kc	-106	-34	-27	+1.8	28.8	-25	+0.8	25.8
	5	4	2		-106	-34	-27	+1.8	28.8	-25	+0.8	25.8
	6	4	Comb			-34	-29	+1.8	30.8	-29	+0.8	29.8
2	1	1	1	500 kc	-106	-33	-18	+1	19	-26	+2	28
	2	1	2		-106	-33	-20	+1	21	-27	+2	29
	3	1	Comb			-33	-20	+1	21	-28	+2	30
1	7	6	1	1.5 mc	-105	-34	-26	+1.8	27.8	-22	+0.8	22.8
	10	6	2		-105	-34	-27	+1.8	28.8	-22	+0.8	22.8
	11	6	Comb			-34	-28	+1.8	29.8	-25	+0.8	25.8
2	7	5	1	1.5 mc	-104.5	-33	-18	+1	19	-26	+2	28
	8	5	2		-104	-33	-16	+1	17	-26	+2	28
	9	5	Comb			-33	-22	+1	23	-28	+2	30

of ±125 KHz. Recorded telemetry data included predetection LHC and RHC channels, predetection combined and post-detection LHC. The ground station radiated -80 dBm at the directional coupler at the start of the run, then decreased the level in 5 dB steps to break lock. At each step, modulation was removed for 15 seconds to allow measurement of noise. The signal was increased in 5 dB steps until the A/RIA reached Point 5 in the pattern. (See Section 3. 1. 3, Flight Patterns.)

During this test, the A/RIA used a 300 KHz IF bandwidth filter and a 100 KHz video filter for post-detection data. The magnetic tapes were reduced in the normal manner, using a 100 KHz video filter for both predetection and post-detection data. Predetected data was direct to the recorder while post-detected data was recorded FM.

Test Results

This test was performed on Flight 31, Data Run 3. A tabular listing of measured results is given in Table XXI. These results are plotted versus the computed output SNR in Figure 59.

Analysis of the curve indicates that system performance is comparable to theoretical performance at SNR's above 10 dB in the receiver IF (-102. 8 dBm at the antenna load). Below 10 dB, the results are not predictable. The predetection output of Channel 2 follows the theoretical curve from the 10-dB threshold up to approximately 20-dB predetection SNR, where the receiver begins to peak out. The likely reason why the Channel 2 curve is below the theoretical is high man-made noise, as discussed in NOTE 2 at the end of this section. The predetection combined output is approximately 3 dB above the uncombined, as expected.

3. 5. 1. 11 VHF System Performance —— Test 6

Receive and record VHF telemetry data, PCM/FM, 51. 2 KBPS, ±125 KHz deviation from the NASA C-121.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal power.

Conditions

The A/RIA flew a standard flight pattern against the C-121 (see Section 3. 1. 3, Flight Patterns), at an altitude of 18, 000 feet terrain clearance. The C-121 flew at 20, 000 feet terrain clearance. Telemetry data were received at 237. 8 MHz, PCM/FM, 51. 2 KBPS, with an FM carrier deviation of 125 KHz. Recorded telemetry data included predetection LHC and RHC channels, predetection combined and post-detection LHC. The A/RIA was configured with a 300-KHz IF bandwidth filter, and a 100-KHz video filter for post-detection data. The magnetic tapes were reduced using a 100-KHz video filter.

TABLE XXI

VHF Data, SNR Versus Input Power Level

Measurement Number	Measured Signal Level Dir. Coupler (dBm)	Data S+N/N (dB) TLM RCVR #4 CH 1 Pre-D (dB)	CH 2 Pre-D (dB)	Comb. Pre-D (dB)	CH 1(A) Post-D (dB)	Computed SNR (NOTE 1) (dB)
1	- 81	32.5	32	35.5	35	40
2	- 86	29.5	30	33.5	31	35
3	- 91	27.5	27	29.5	29	30
4	- 95	22.5	23	25.5	24	25
5	-101	18.5	18	20.5	20	20
6	-104.5	12.5	13	14.5	13	14.7
7	-111	9.5	7	11.5	10	7.3
8	-112	2.5	2	4.5	3	0.8
9	-108	7.5	7	10.5	8	7.3
10	-103.5	14.5	14	17.5	11	14.7
11	- 99	18.5	18	21.5	21	20.0

(A) Only CH-1 Post-Detected data was recorded.

Test Results

This test was performed on Flight 29, Data Runs 1 and 6, and Flight 30, Data Runs 1 and 6. Flight 29 was over land near Tulsa, and Flight 30 over the Gulf of Mexico. The test results are shown in Table XXII. Analysis of the results indicates that the noise level was lower during Flight 30, the over-water flight. This can be determined by comparing each of the measured S+N/N ratios on Flight 29 to the computed values, and by comparing each of the S+N/N ratios from Flight 30 to the computed values. A discussion of high man-made noise over Tulsa is included in NOTE 2. The post detection outputs are higher than the predetection outputs because of additional filtering of data. Overall, system performance was essentially as expected.

TABLE XXII

VHF Data, SNR Versus Power Level, C-121 Source

FLT No.	RUN No.	Meas. No.	Measured Signal Level at Directional Coupler (dBm)		Data S+N/N (dB) TLM RCVR #4				(NOTE 1) Computed SNR (dB)	
			CH 1	CH 2	CH 1 Pre-D (dB)	CH 2 Pre-D (dB)	COMB Pre-D (dB)	CH 1 (A) Post-D (dB)	CH 1	CH 2
29	1	1	-82	-83	35	33	38	39	36.4	35.4
		2	-82	-83	35	33	38	39	36.4	35.4
		3	-82	-83	35	33	38	40	36.4	35.4
		4	-82	-83	35	33	38	40	36.4	35.4
29	6	1	-87	-90	32.5	30.5	33.5	36.5	31.4	28.4
		2	-87	-90	32.5	30.5	34.0	36.5	31.4	28.4
		3	-86	-90	33.5	31.5	34.5	38.5	32.4	28.4
		4	-86	-90	34.5	31.5	35.5	39.5	32.4	28.4
30	1	1	-84	-83	36.5	37.5	37.5	42	34.4	35.4
		2	-85	-83	35.5	37.5	37.5	39	33.4	35.4
		3	-85	-81	35.5	38.5	37.5	39	33.4	36.4
		4	-84	-81	36.5	39.5	38.5	39	34.4	36.4
30	6	1	-97	-96	25.5	27.5	28.5	34	21.4	22.4
		2	-96	25.5	28.5	29.5	33	21.4	22.4	
		3	-97	-96	25.5	27.5	29.5	33	21.4	22.4

(A) The Post-Detected Data from Channel 2 was not recorded.

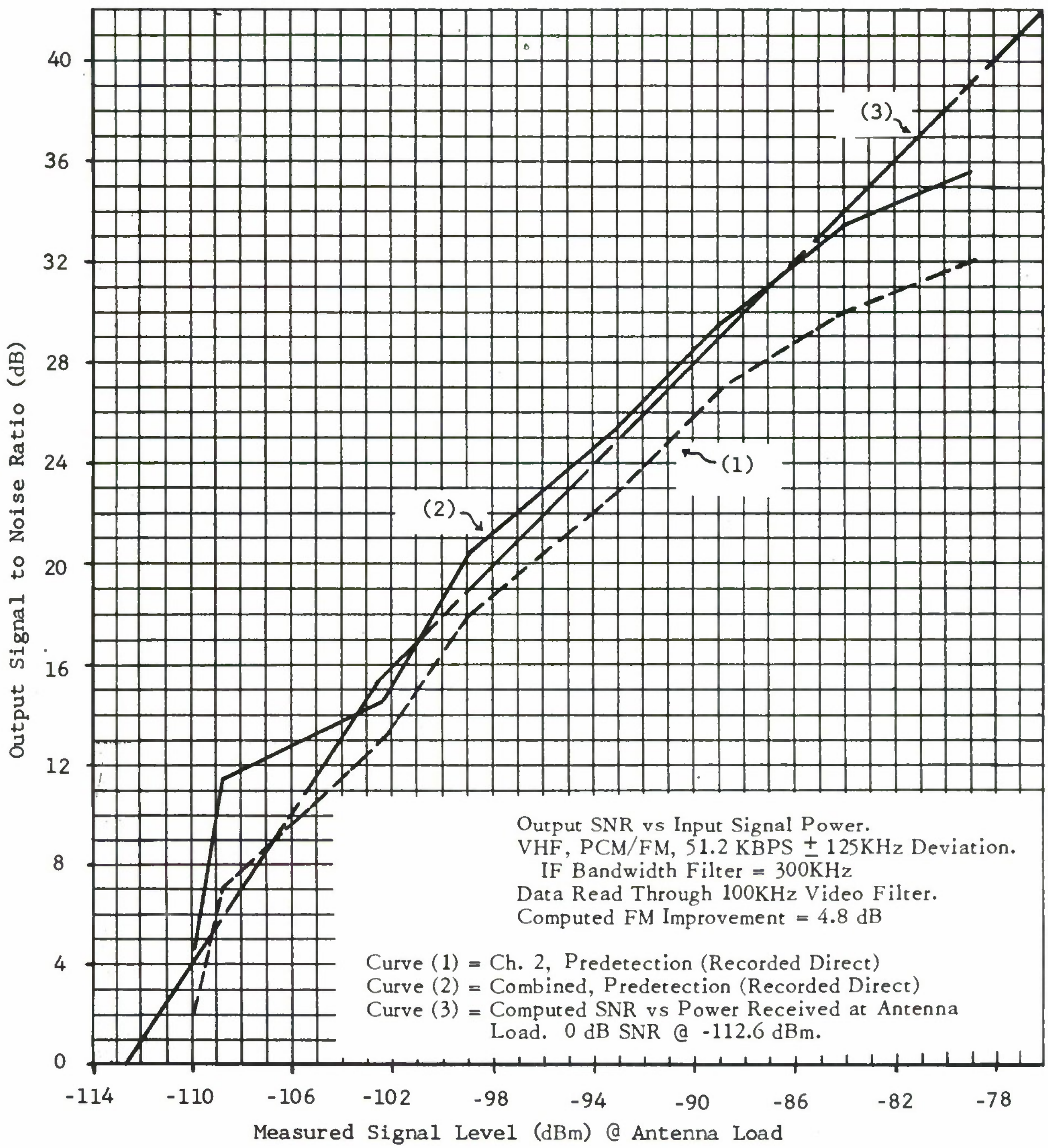


FIGURE 59. VHF DATA, CALCULATED VS MEASURED OUTPUT SNR

3.5.1.12 Notes for Section 3.5.1

NOTE 1

Computation of data SNR for VHF, PCM/FM, 51.2 KBPS and 1.6 KBPS (±125-KHz deviation).

Example: Pr = -100 dBm (P_{DC} = -102 dBm)

Predetection SNR

Φ KT (Spectral Noise Density)(NOTE 28, Sec. 3.12.3)	-167.3 dBm/Hz
Pr (Received Signal Power)	-100.0 dBm
Predetection noise bandwidth (300 KHz)	- 54.8 dB
Predetection SNR	12.5 dB

Post-detection SNR, 51.2 KBPS

Predetection SNR	12.5 dB
FM Improvement 10 log $\left[3 \left(\frac{\Delta f}{b}\right)^2\right]$	
10 log $\left[3 \left(\frac{125}{125}\right)^2\right]$	4.8 dB *
Video/IF bandwidth improvement	
(Video Filter = 125 KHz)	
10 log $\frac{B}{2b} = \frac{300}{250}$	0.8 dB
	18.1 dB

*For predetection SNR values below 10 dB, a threshold loss of 0.48 (10-Pre-D SNR) is used.

Post-detection SNR, 1.6 KBPS

Predetection SNR	12.5 dB
FM Improvement 10 log $\left[3\left(\frac{\Delta f}{b}\right)^2\right]$	
10 log $\left[3\left(\frac{125}{3}\right)^2\right]$	37.2 dB
Video/IF bandwidth improvement	
(Video Filter = 3 KHz)	
10 log $\frac{B}{2b} = \frac{300}{6}$	16.9 dB
	66.6 dB

NOTE 2

Derivation of a tolerance to compare measured SNR's to computed SNR's. Assume an FM improvement of 4.8 dB.

Received Signal Power at Directional Coupler	Tolerance
-114.6 dBm to -104.6 dBm	4 $\pm$ 3 dB
-104.6 dBm to -70 dBm	4 $\pm$ 2 dB

Below -104.6 dBm, a 1-dB variation in signal level will result in a 1.48 dB variation in output SNR because of FM improvement. All computations assume that 0-dB SNR in the IF (at -114.6 dBm at dc) is coincident with 0-dB output SNR.

A special data run was made to determine the level of man-made noise in the standard racetrack in the Tulsa area. When the antenna was moved from zenith to approximately -1° elevation, an increase of 4 dB in noise was measured. This noise level will degrade SNR values measured at a specific power level.

NOTE 3

Computation of data SNR for PCM/FM, 72 KBPS ($\pm$39-KHz deviation).

Example: Pr = 100 dBm (P_{DC} = -102 dBm)

Predetection SNR

Φ KT (Spectral Noise Density) (NOTE 28, Sec. 3.12.3)	-167.3 dBm/Hz
Pr (Received Signal Power)	-100.0 dBm
Predetection noise bandwidth (300 KHz)	- 54.8 dB
Predetection SNR	12.5 dB

Post-detection SNR

Predetection SNR 12.5 dB

FM Improvement $10 \log \left[3 \frac{\Delta f}{b}^2\right]$

$$10 \log \left[3 \frac{39}{125}^2\right] \qquad - \; 5.4 \text{ dB}$$

Video/IF Bandwidth improvement

(Video Filter = 125 KHz)

$$10 \log \frac{B}{2b} = \frac{300}{250} \qquad 0.8 \text{ dB}$$

7.9 dB

3.5.2 Receive and Record UHF Telemetry Data (Except Unified S-Band)

3.5.2.1 Test Result Summary

UHF telemetry data were successfully received and recorded, PCM/FM, at S-Band and L-Band. Both systems performed as expected. The L-Band system yielded an output SNR from 7.5 dB to 19 dB at received power levels of -103.5 dBm to -91 dBm, respectively, referenced to the antenna load. No coded PCM data were recorded on UHF other than Unified S-Band.

3.5.2.2 Tests Performed

Test 1 Receive and record S-Band UHF telemetry data, PCM/FM, 72 KBPS, ±35-KHz deviation, from the ground station.

Test 2 Receive and record L-Band UHF telemetry data, PCM/FM, 51.2 KBPS, ±125-KHz deviation, from the ground station.

3.5.2.3 Test Environment

UHF telemetry data (except Unified S-Band) were received and recorded from the Tulsa ground station. A discussion of the ground station facility and the control of signals transmitted is included in Sections 3.1.4 and 3.1.5.

3.5.2.4 Data Collection Techniques

Signal plus noise-to-noise measurements of UHF telemetry data were taken from operator readings and from the magnetic tapes recorded during the data runs. Readings of predetection and post-detection signals were accomplished, using the configuration shown in Figure 57.

The received signal levels under the Test Results section were measured from oscillograph records. Calibration of AGC to derive signal strength is discussed in Section 3.1.5.

3.5.2.5 System Configuration

The A/RIA PMEE configuration used for these tests is shown in Figures 60 and 61. Figure 60 shows the receive and record configuration used for S-Band PCM/FM signals; this is the narrow-band UHF channel (2200 to 2300 MHz). Figure 61 represents the receive and record configuration used for L-Band PCM/FM signals; this is the wideband UHF channel (1400 to 2300 MHz).

In Figure 60, the LHC and RHC signals are received at the UHF antenna, amplified by the parametric and TWT amplifiers and fed to the UHF multicouplers. The multicoupler outputs are fed to the tracking receivers and the UHF telemetry receivers. The LHC signal is fed to Channel 1 of the telemetry receiver and the RHC signal fed to Channel 2. The receiver predetected outputs were patched to direct record modules and recorded on the wideband recorder; post-detected signals were patched through FM record modules to the recorder.

The wideband UHF channel utilized for L-Band operation (shown in Figure 61) is similar to that discussed above. The major difference is that only the TWT is used as a preamplifier.

3.5.2.6 UHF System Performance —— Test 1

Receive and record S-Band UHF telemetry data, PCM/FM, 72 KBPS, ±35-KHz deviation, from the ground station.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal power.

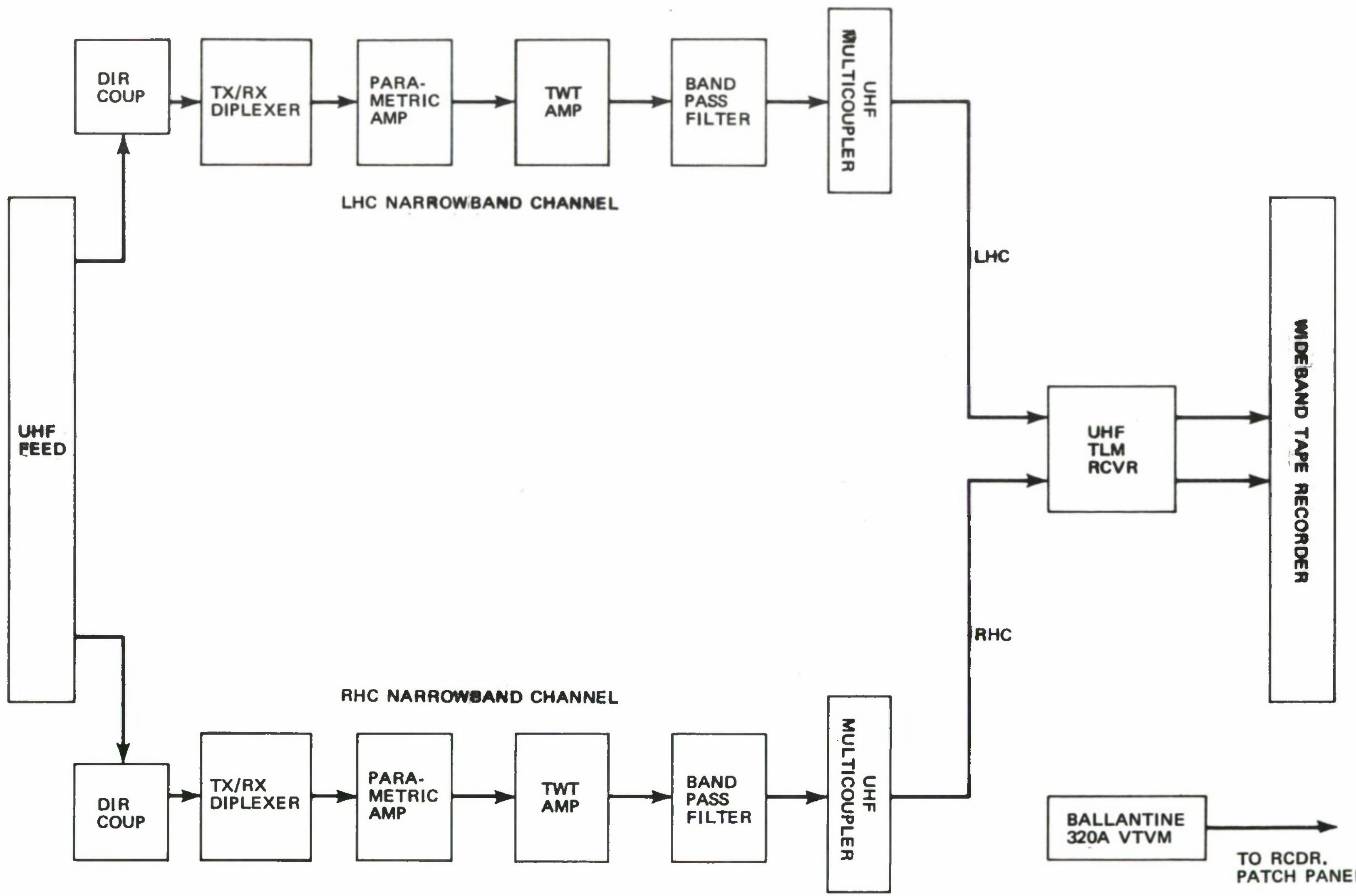


FIGURE 60. SYSTEM CONFIGURATION FOR UHF PCM/FM DATA

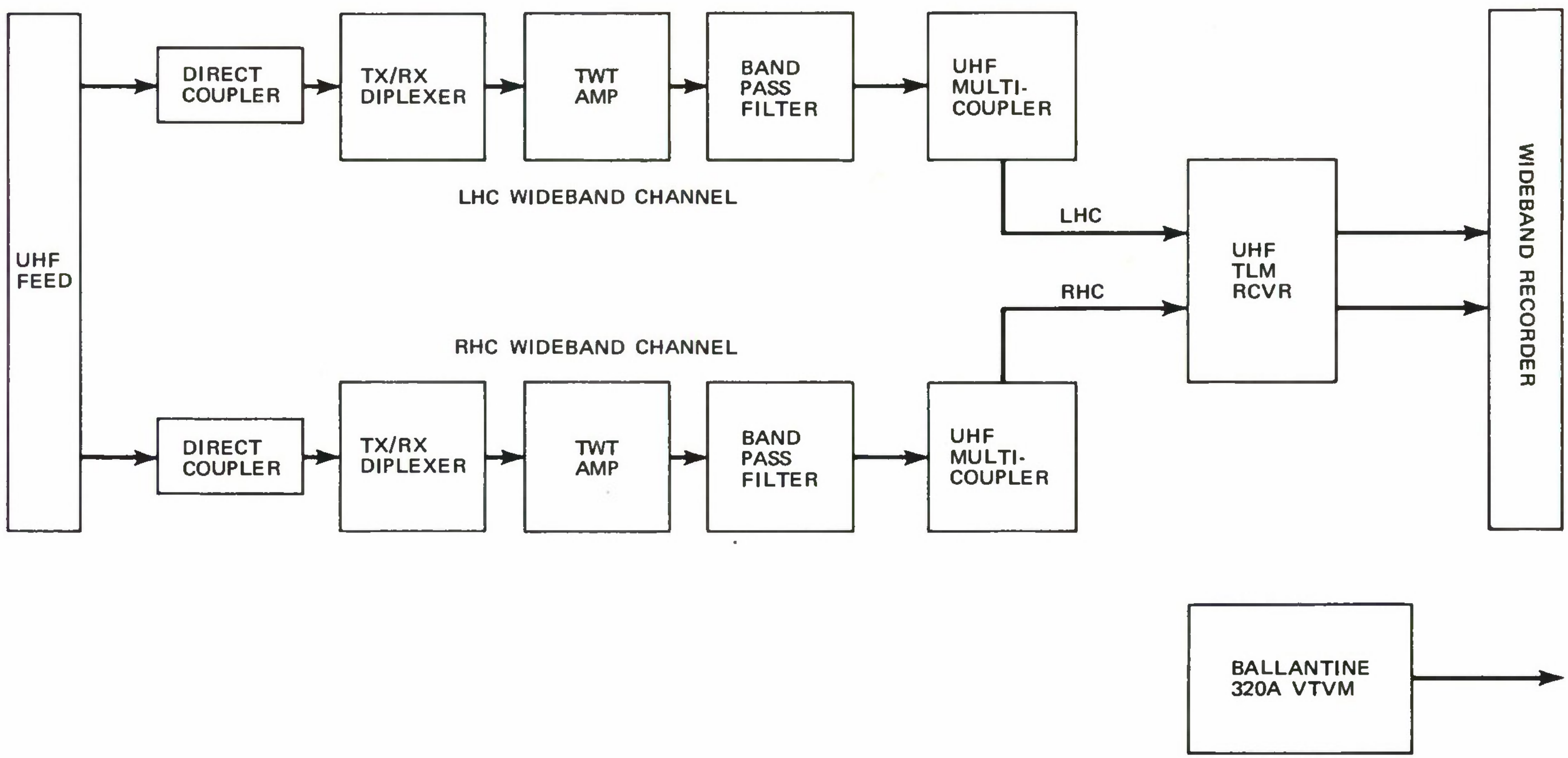


FIGURE 61. SYSTEM CONFIGURATION FOR L-BAND TLM DATA

Conditions

This test was performed during Flight 19, Data Runs 3 and 8. Run 1 was a standard racetrack pattern while Run 8 was a crosstrack pattern. Telemetry data were received at 2287.5 MHz, PCM/FM, 72 KBPS, with a ±35-KHz carrier deviation. The UHF telemetry receiver used a 300-KHz IF bandwidth filter and the data were read through a 100-KHz video filter.

Test Results

The test results are shown in Table XXIII. Telemetry data recorded on the wideband recorder during this flight were defective because of operator error. The readings listed in the table were taken by the record operator from the Record Patch Panel with a Ballantine 320A VTVM. Comparison of the measured readings (converted to SNR) to the computed indicate the results are as predicted, within the established tolerance. The computed values were derived as outlined in NOTE 1 at the end of this section.

TABLE XXIII

UHF Data - SNR Versus Power Level (72 KBPS, PCM/FM)

Data Run No.	Measurement No.	Measured Signal Power at Directional Coupler (dBm)		Measured S+N/N Converted to SNR*		Computed SNR (dB) (NOTE 1)	
		CH 1	CH 2	CH 1	CH 2	CH 1	CH 2
3	1	-107	-106	4(1.8)	5(3.3)	2.4	3.8
	2	-107	-106	4(1.8)	5(3.3)	2.4	3.8
8	1	-90	-88	22.5	19	20	22
	2	-92	-93	22.5	19	18	17
	3	-92	-91	22.5	19	18	19

The computation for the computed SNR is included at the end of Section 3.5.2 as NOTE 1.

*At low S+N/N ratios, it is necessary to convert the measured values to SNR using the formula SNR = $\frac{S+N}{N}$ -1, with all values in power ratios. Applying this conversion to the results of Data Run 3, thus:

SNR = 2.512 SNR = 3.162-1

SNR = 1.512 = 1.8 dB SNR = 2.162 = 3.3 dB

The modulation scheme tested is one used by the Apollo S-IVB stage. The combination of a relatively high bit rate (72 KBPS) and a small carrier deviation results in a negative FM improvement.

3.5.2.7 UHF System Performance —— Test 2

Receive and record L-Band UHF telemetry data, PCM/FM, 51.2 KBPS, ±125-KHz deviation, from the ground station.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal power.

Conditions

This test was performed during Flight 31, while the A/RIA flew a standard racetrack pattern. Telemetry data were received at 1501.0 MHz, PCM/FM, 51.2 KBPS, with a ±125-KHz carrier deviation. The UHF telemetry receiver used a 300-KHz IF bandwidth filter and the data were read through a 100-KHz video filter. All readings included under Test Results were taken from wideband recorder tapes, using the configuration shown in Figure 57.

Test Results

Telemetry data at L-Band were received and recorded during Data Runs 1 and 2. The results are shown in Table XXIV. The measured values compare to the computed within the established ±2 dB tolerance. Combiner action on Data Run 1 resulted in a 3-dB improvement with the two uncombined signals having the same SNR. This agrees with the theoretical maximum improvement of 3 dB gained by coherently combining equal signals. The combiner provided a 2-dB improvement on Data Run 2; however, the uncombined channels were not equal. The post-detected outputs are better than the predetected because of additional filtering.

During Data Run 3, the L-Band received signal power was decreased from a measured -93 dBm at the directional coupler down to -105.5 dBm. Modulation was removed at each level to permit noise measurements. The results of this test are given in Table XXV and plotted in Figure 62. The received signal power on the curve is referenced to the antenna load rather than the directional coupler.

The Channel 1 uncombined SNR versus input power curve is comparable to the theoretical over the range tested. The combined curve shows an improvement of 2 dB to 3 dB over the uncombined.

TABLE XXIV

UHF Data — SNR Versus Power Level (L-Band Source)

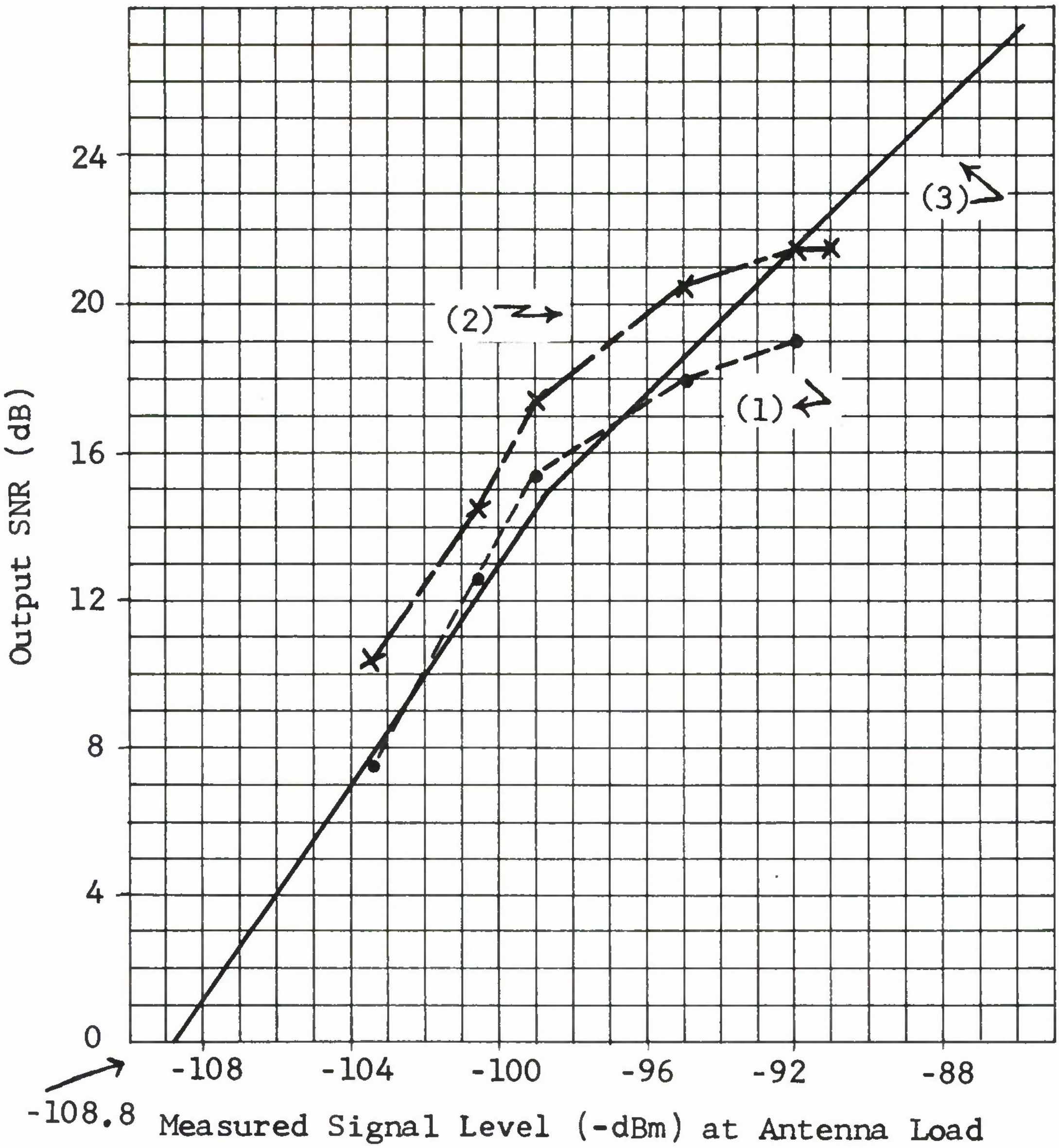
Data Run No.	Signal	Measured Signal Power at Direct. Coupler (-dBm)	Measured S+N/N from tape (dB)	Computed SNR NOTE 2
1	CH-1, Pre-D	- 96.5	17.5	19.9
	CH-2, Pre-D	- 96.5	17.5	19.9
	COMB, Pre-D		20.5	
2	CH-1, Pre-D	-100.5	15.5	15.9
	CH-2, Pre-D	-100.5	16.0	15.9
	COMB, Pre-D		18.0	
	CH-1, Post-D	-100.5	16.5	15.9
	CH-2, Post-D	-100.5	17.0	15.9

The computation for the computed SNR is included at the end of Section 3.5.2 as NOTE 2.

TABLE XXV

UHF Data - SNR Versus Input Power Level (L-Band Source)

Measure-ment Number	Measured Signal Level at Directional Coupler (dBM)	Data S+N/N (dB), TLM RCVR No. 2					Computed SNR NOTE 2	
		CH-1 Pre-D	CH-2 Pre-D	COMB Pre-D	CH-1 Post-D	CH-2 Post-D	CH-1	CH-2
1	- 93	18.5	19	21.5	19.5	20.5	22.5	22.5
2	- 94	19	19.5	21.5	20.5	20.5	21.5	21.5
3	- 97	18	18	20.5	19	19	18.5	18.5
4	-101	15.5	15.5	17.5	17	16	14.5	14.5
5	-102.5	12	12	14.5	13	12	12.5	12.5
6	-105.5	7.5	7.5	10.5	8	8.5	7.8	7.8



Output SNR vs. Input Signal Power
L-Band, PCM/FM, 51.2KBPS, ± 125KHz Deviation
IF Bandwidth Filter = 300 KHz
Data Read Through 100KHz Video Filter
Computed FM Improvement = 4.8 dB

Curve (1) Channel 1, Predetection (Recorded Direct)
Curve (2) Combined, Predetection (Recorded Direct)
Curve (3) Computed SNR vs. Power Received at Antenna Load
ODB SNR = 108.8 dBm

FIGURE 62. UHF DATA, CALCULATED VS MEASURED OUTPUT SNR

3.5.2.8 Notes for Section 3.5.2

NOTE 1

Computation of data SNR for UHF, PCM/FM, 72 KBPS, $\pm$ 35-KHz deviation.

Example: P_r = -100 dBm (-102 dBm at the directional coupler)

Predetection SNR

ΦKT (Spectral Noise Density) (NOTE 10, Sec. 3.12.3)	-168.3 dBm/Hz
P_r (Received Signal Power)	-100.0 dBm
Predetection noise bandwidth (300 KHz)	- 54.8 dB
Predetection SNR	+ 13.5 dB

Post-detection SNR

Predetection SNR	+ 13.5 dB
FM Improvement $10 \log \left[3 \left(\frac{\Delta f}{b}\right)^2\right]$	
$10 \log \left[3 \left(\frac{35}{125}\right)^2\right]$	- 6.2 dB
Video/IF Bandwidth Improvement	
Video Filter = 125 KHz - (3 dB)	
$10 \log \frac{B}{2b} = \frac{300}{250}$	+ .8
Output SNR	8.1 dB

NOTE 2

Computation of data SNR for UHF (L-Band), PCM/FM, 51.2 KBPS, $\pm$125-KHz deviation.

Example: P_r = -100 dBm (-102 dBm at the directional coupler)

Predetection SNR

ΦKT (Spectral Noise Density) (NOTE 32, Sec. 3.12.3)	-163.6 dBm/Hz
P_r (Received Signal Power)	-100.0 dBm
Predetection noise bandwidth (300 KHz)	- 54.8 dB
Predetection SNR	+ 8.8 dB

Post-detection SNR

Predetection SNR	+ 8.8 dB
FM Improvement $10 \log \left[3 \left(\frac{\Delta f}{b} \right)^2 \right]$	
$10 \log \left[3 \left(\frac{125}{125} \right)^2 \right]$	+ 4.8 dB
Threshold Loss: .48 (10-Pre-D SNR)	
.48 (1.2)	- 0.6
Video/IF Bandwidth Improvement	
$10 \log \frac{B}{2b} = \frac{300}{250}$	+ 0.8
Output SNR	+ 13.8 dB

3.5.3 Receive and Record Unified S-Band Telemetry Data

3.5.3.1 Test Result Summary

Unified S-Band telemetry data were successfully received and recorded on several Category II flights. Output SNR's for 51.2-KBPS data of 8.5 dB to 12 dB were recorded at the specification power level of -103.5 dBm at the antenna load. Output SNR's for 1.6-KBPS data of 23 dB and 26 dB were measured at power levels of -106 dBm and -104 dB, respectively. Output SNR's up to 40.5 dB were measured with 51.2-KBPS data at a received power of -76 dBm. Test results indicate that the USB system gives a slight SNR enhancement due to coherent detection.

The recorded data were evaluated by analyzing SNR versus received signal power. Although a coded PCM pulse train was recorded on two flights, no bit error was performed on the tapes.

UHF telemetry system reliability was satisfactory.

3.5.3.2 Unified S-Band Tests Performed

Test 1 Receive and record Unified S-Band telemetry data, PCM/PM/PM, 51.2 KBPS from the ground station.

Test 2 Derive a curve of output SNR versus input signal power from -97 dBm to -110 dBm for Unified S-Band data, PCM/PM/PM, 51.2 KBPS.

Test 3 Receive and record Unified S-Band telemetry data, PCM/PM/PM, 1.6 KBPS from the ground station.

Test 4 Receive and record Unified S-Band telemetry data, PCM/PM/PM, 51.2 KBPS from the NASA C-121 Apollo Simulator.

3.5.3.3 Test Environment

Unified S-Band telemetry data were received and recorded from the Tulsa ground station and the NASA C-121 during the Category II Flight Test Program. A discussion of these facilities, and the control of signals transmitted from them, is included in Sections 3.1.4 and 3.1.5, respectively.

3.5.3.4 Data Collection Techniques

Signal plus noise-to-noise measurements of Unified S-Band telemetry data were taken during flight by the Record Operator with a Ballantine 320 VTVM, as shown in Figure 63. The modulation on the data subcarrier was turned off at intervals during the data run to provide for noise readings.

Signal plus noise-to-noise measurements were also taken from the magnetic tapes recorded during the data runs. All readings were of data recorded post-detection (baseband) FM to the recorder. The test configuration for playback of the magnetic tapes is shown in Figure 57.

The received signal levels presented under Test Results were measured and reduced from oscillograph records. Calibration of AGC to derive signal strength is discussed in Section 3.1.5.

3.5.3.5 System Configuration

The A/RIA PMEE configuration used to receive and record Unified S-Band telemetry data is shown in Figure 63. The signals received by the UHF antenna are amplified by the parametric and TWT amplifiers in the LHC and RHC sum channels and fed to the UHF multicouplers. The LHC multicoupler output is fed to UHF track receiver 2 and the RHC multicoupler output fed to track receiver 4. The receiver IF bandwidth filters used were 3.3 MHz. The 1.024-MHz data subcarriers were patched to the data demodulators. The post-detected PCM pulse train was recorded FM to the recorder.

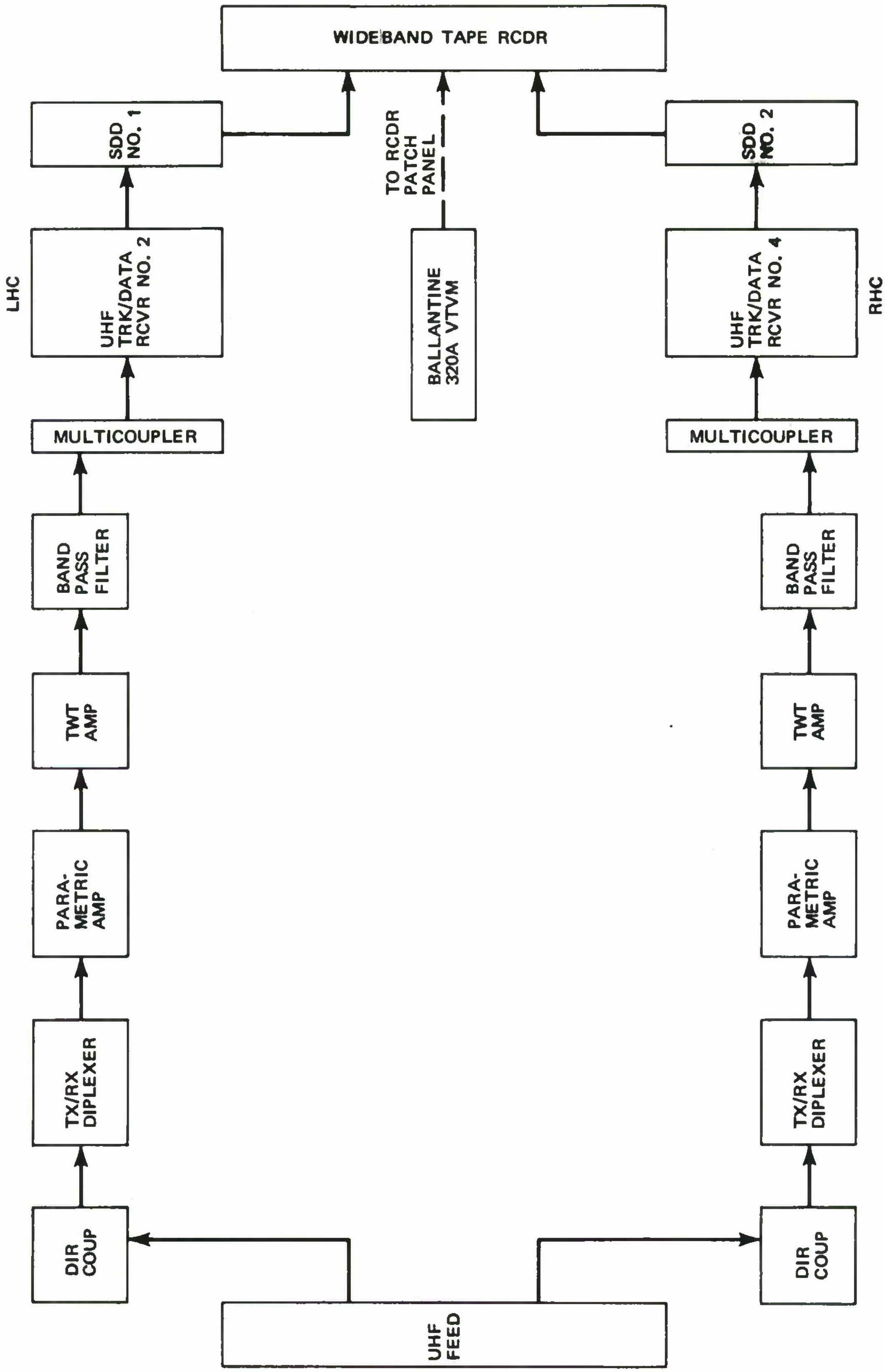


FIGURE 63. UNIFIED S-BAND SYSTEM CONFIGURATION

3.5.3.6 Unified S-Band System Performance —— Test 1

Receive and record Unified S-Band telemetry data, PCM/PM/PM, 51.2 KBPS from the ground station.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal power used.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data was received at 2287.5 MHz, PCM/PM/PM. The 51.2 KBPS data was bi-phase modulated on a 1.024 MHz subcarrier at a PM deviation of ±1.57 radians, while the data subcarrier modulated the carrier at a PM deviation of 1.1 radians. The receiver IF bandwidth was 3.3 MHz, the subcarrier predetection bandwidth 150 KHz, and the subcarrier post-detection bandwidth 75 KHz. The system was tracking on UHF with a tracking loop bandwidth of 1000 Hz.

Test Results

Telemetry data from Flights 20 and 25 were reduced from magnetic tapes and are presented in Table XXVI.

TABLE XXVI

Unified S-Band SNR (Magnetic Tape Reduction)

Flt. No.	Run No.	Measurement Number	Measured Signal Power (-dBm) at Directional Coupler		Measured S+N/N (dB)		Computed SNR (dB) (NOTE 1)	
			LHC	RHC	LHC	RHC	LHC	RHC
20	1	1	-105.5		8.5		8.9	
		2	-104.5		9.5		9.9	
25	2	1	-107	-105	10.5	12.0	7.4	9.4
		2	-107	-105	10.5	12.0	7.4	9.4

Telemetry data S+N/N were taken by the Record Operator on Flights 15 and 22. These data are presented in Table XXVII.

TABLE XXVII

Unified S-Band SNR (Operator Readings)

Flight No.	Run No.	Measurement No.	Measured Signal Power at Directional Coupler (-dBm)		Measured S+N/N (dB)		Computed SNR (dB) (NOTE 1)	
			LHC	RHC	LHC	RHC	LHC	RHC
15	1	1	-82	- 78	34	40.5	32.4	36.4
		2	-82	- 78	34	40.5	32.4	36.4
		3	-82	- 78	34	40.5	32.4	36.4
		4	-82	- 78	34	40.5	32.4	36.4
15	6	1	-80	- 80	35	39.5	34.4	34.4
		2	-80	- 80	35	39.5	34.4	34.4
		3	-80	- 80	35	39.5	34.4	34.4
		4	-80	- 80	35	39.5	34.4	34.4
22	2	1		-108.2		7.5*		6.2
		2		-107		9.0*		7.4
		3		-101		15.0		13.4

*7.5 dB corrected to 6.7 dB, and 9.0 dB corrected to 8.4, by the formula:

$$SNR = \frac{S+N}{N} - 1$$

A tolerance of ± 2 dB is allowed for measuring received signal power. This results in a tolerance of ± 2 dB when comparing measured S+N/N ratios to computed SNR's.

The test results indicate a coherent detection SNR enhancement with the Unified S-Band system. All readings are equal to or better than those computed (see NOTE 1).

3.5.3.7 Unified S-Band System Performance —— Test 2

Derive a curve of output SNR versus input signal power from -97 dBm to -110 dBm for Unified S-Band data, PCM/PM/PM, 51.2 KBPS.

Specification/Goal

Compare the measured curve to the computed curve.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data were received at 2287.5 MHz, PCM/PM/PM. The 51.2-KBPS data were bi-phase modulated on a 1.024-MHz subcarrier at a PM deviation of ±1.57 radians, while the data subcarrier modulated the carrier at a PM deviation of 1.1 radians. The receiver IF bandwidth was 3.3 MHz, the subcarrier predetection bandwidth was 150 KHz, and the subcarrier post-detection bandwidth was 75 KHz. The system was tracking on UHF with a tracking loop bandwidth of 1000 Hz. The signal was attenuated by the ground station in steps of approximately 3 dB each.

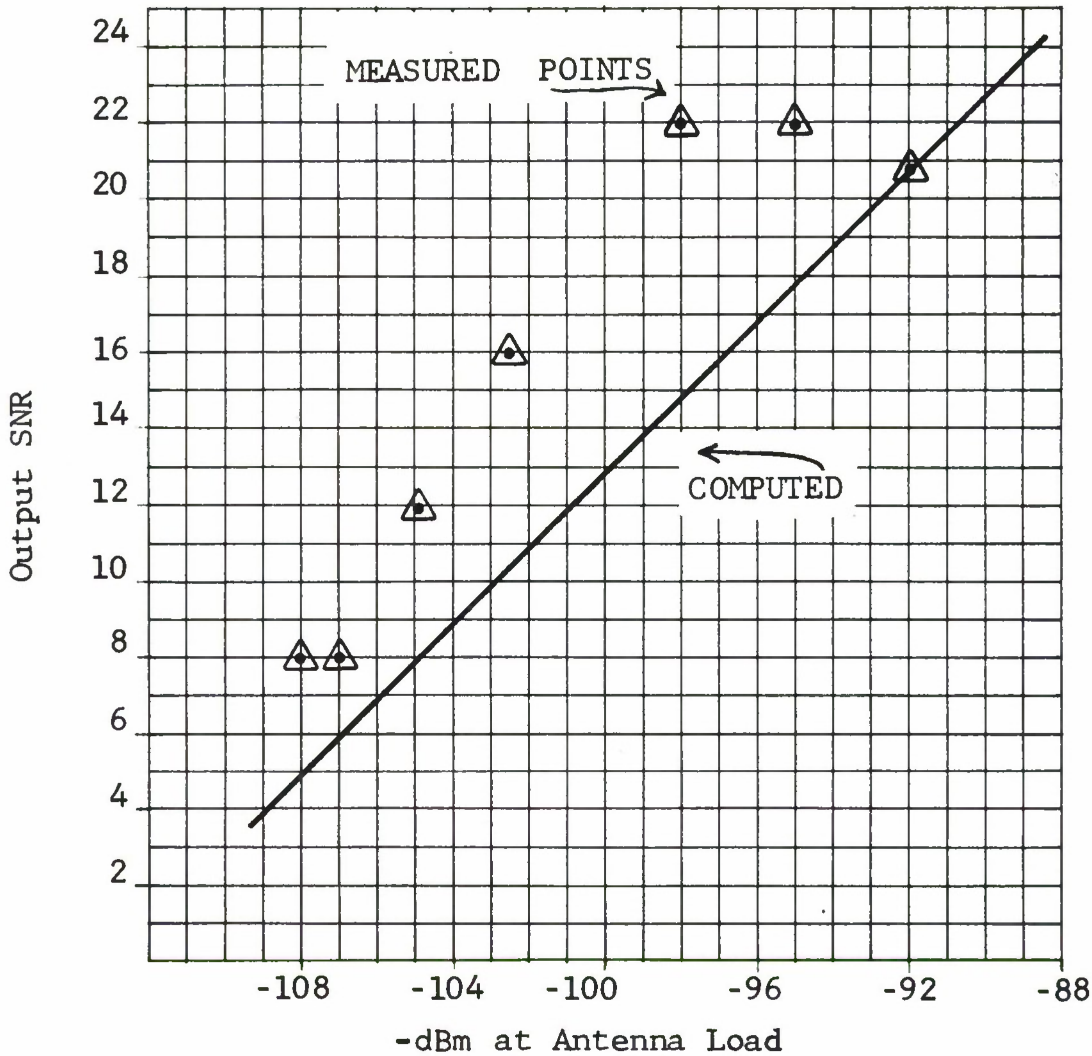
Test Results

This test was performed on Flight 25, Data Run 6. A tabular listing of results is given in Table XXVIII. The results are plotted versus the computed output SNR in Figure 64. The signal levels in the figure are referenced to the antenna load. The tolerance in comparing measured to computed values is ±2 dB (received signal power measurement accuracy).

TABLE XXVIII

Unified S-Band SNR Versus Input Power Level

Measurement Number	Measured Signal Level at Directional Coupler (RHC) (-dBm)	Measured S+N/N (dB)	Computed SNR (dB)
1	-97	22	17.4
2	-100	22	14.4
3	-104.5	16	9.9
4	-107	12	7.4
5	-109	8	5.4
6	-110	8	4.4



Output SNR vs. Received Signal Power
Unified S-Band, PCM/PM/PM, 51.2KBPS Data
Data PM on Subcarrier at ±1.57 RAD. (Subcarrier f=1.024MHz)
Subcarrier PM on Carrier at ±1.1 RAD. (Carrier f=2287.5MHz)
IF Bandwidth Filter = 3.3MHz
Pre-D Bandwidth (DATA) = 150KHz
Post-D Bandwidth (DATA) = 75KHz

FIGURE 64. UNIFIED S-BAND DATA, CALCULATED VS MEASURED OUTPUT SNR

The results of the Unified S-Band tests indicate that the system gives a coherent detection signal enhancement. Measured S+N/N ratios are consistently higher than the computed.

3.5.3.8 Unified S-Band System Performance —— Test 3

Receive and record Unified S-Band telemetry data, PCM/PM/PM, 1.6 KBPS, from the ground station.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal level.

Conditions

The A/RIA flew a standard racetrack pattern against the ground station. Telemetry data were received at 2287.5 MHz, PCM/PM/PM. The 1.6-KBPS data were bi-phase modulated on a 1.024-MHz subcarrier at a PM deviation of ±1.57 radians, while the data subcarrier modulated the carrier at a PM deviation of 1.1 radians. The receiver IF bandwidth was 3.3 MHz, the subcarrier predetection bandwidth 6 KHz, and the subcarrier post-detection bandwidth 3 KHz. The system was tracking on UHF with a tracking loop bandwidth of 1000 Hz.

Test Results

This test was performed on Flight 24, Data Run 5. Test results, read from magnetic tapes, are shown in Table XXIX.

TABLE XXIX

Unified S-Band Telemetry Data, 1.6 KBPS

Measured Signal Level at Directional Coupler (-dBm)		Measured S+N/N (dB)		Computed SNR (NOTE 1) (dB)	
LHC	RHC	LHC	RHC	LHC	RHC
-108	-106	23	26	19.4	21.4

As noted in Tests 1 and 2 in this section, the measured signal-to-noise ratios are above the computed values because of SNR enhancement due to coherent detection.

3.5.3.9 Unified S-Band System Performance —— Test 4

Receive and record Unified S-Band telemetry data, PCM/PM/PM, 51.2 KBPS from the NASA C-121 Apollo Simulator.

Specification/Goal

Compare the SNR of the recorded data to the computed value at each received signal level.

Conditions

The A/RIA flew a racetrack pattern against the C-121, as discussed in Section 3.1.3 (Flight Patterns). Telemetry data were received at 2287.5 MHz, PCM/PM/PM. The 51.2 KBPS data were bi-phase modulated on a 1.024-MHz subcarrier at a PM deviation of ±1.57 radians, while the data subcarrier modulated the carrier at a PM deviation of 1.1 radians. The receiver IF bandwidth was 3.3 MHz, the predetection bandwidth was 150 KHz, and the post-detection bandwidth was 75 KHz. The system was tracking on UHF with a tracking loop bandwidth of 1000 Hz.

Test Results

Table XXX gives the results from Data Run 6 of Flight 30.

TABLE XXX

Unified S-Band Telemetry Data, C-121 Source

Measurement Number	Measured Signal Level at Directional Coupler (-dBm)		Measured S-N/N (-dB)		Computed SNR (dB) (NOTE 1)	
	LHC	RHC	LHC	RHC	LHC	RHC
1	-94	*	19.5	*	20.4	*
2	-93		21.5		21.4	
3	-89		27.5		25.4	

* Data demodulator Number 2 did not lock up.

It was planned to take Unified S-Band data signal-to-noise ratios during a total of three data runs during Flights 29 and 30; however, on the other two runs the C-121 operator turned off the subcarriers instead of the modulation. This made a noise measurement impossible, since subcarriers are required to achieve quieting. During the balance of the runs, modulation was applied at all times, to facilitate bit error measurements. These measurements will be made later by NASA.

3.5.3.10 Notes for Section 3.5.3

NOTE 1

Computation of data SNR for Unified S-Band, 51.2 KBPS and 1.6 KBPS.

Example: Pr = -106 dBm (-108 dBm at the directional coupler)

Predetection SNR	51.2 KBPS	1.6 KBPS
Pr (Received Signal Power)	106.0 dBm	106.0 dBm
Pr_1 (TM Subcarrier) - Modulation Loss	4.1 dB	5.1 dB
Φ_{KT} (Spectral Noise Density)	168.3 dBm/Hz	168.3 dBm/Hz
Predetection noise bandwidth	51.8 dB	37.8 dB
51.2 KBPS (150 KHz)		
1.6 KBPS (6 KHz)		
Predetection SNR	6.4 dB	19.4 dB
Output SNR		
Predetection SNR	6.4 dB	19.4 dB
Predetection/Post-detection Video Filter Improvement		
51.2 KBPS $10 \log \frac{B}{2b} = \frac{150}{150}$	0.0 dB	0.0 dB
1.6 KBPS $10 \log \frac{B}{2b} = \frac{6}{6}$		
Output SNR	6.4 dB	19.4 dB

3.5.4 Functional Reliability/Operability

The VHF telemetry equipment demonstrated good reliability during the test program. In-flight failures compromised telemetry data on Flights 20, 23, and 27; one receiver failed on each flight. A complete listing of failures is available from the Douglas Engineering Reliability Group. The most serious failure experienced was interference at VHF from civilian and military installations in the Tulsa area.

UHF telemetry equipment reliability was also satisfactory. The two items having the highest failure rate were the signal data demodulators and parametric amplifiers. These items are discussed below:

a. On several test flights only one of the two signal data demodulators remained locked up. The lockup was very slow and intermittent on several occasions. The cause of the problem appears to be instability in the VCO used in the phase lock loop. The oscillator has a high frequency drift during flight.

b. Three parametric amplifiers were replaced for low gain. The specific cause of failure was degradation due to lack of preventive maintenance. Handbook procedures have been updated.

Specific tests were often unsuccessful because of improper equipment set up or operator error. These include:

a. The ground station transmitted 2 MHz off frequency on Flight 10, Run 1.

b. The ground station transmitted 1.6 KBPS instead of 51.2 KBPS at a power level of -115 dBm on Flight 12, Run 3.

c. The Record Operator misaligned the recorder on Flight 19.

d. The Telemetry Operator operated Receiver 7 in APC instead of AFC mode on Flight 23.

e. The receiver video output level was misadjusted on some runs.

f. The C-121 operator turned off the data subcarriers instead of the modulation on Flight 29, resulting in no noise reading for S+N/N measurements.

g. The UHF/VHF signal generator used for AGC calibrations was, at times, unstable in power output level, especially at UHF. This resulted in invalid calibrations on several data runs, including the ballistic missile mission.

3.5.5 Design/Operational Problems

3.5.5.1 Signal Data Demodulator VCO Instability

The data demodulator VCO has been unstable, causing intermittent unlocking during flight.

Approved Solution

The following operational and equipment changes have been or will be incorporated to improve the VCO stability:

a. RF Group preflight test procedure No. 2078343 will be modified to include an alignment procedure for the XVCO frequency.

b. The SDD wiring will be modified to permit longer XVCO warm up, accomplished by applying power to the SDD during preflight, takeoff, and climbout.

c. The pull-in range (Hz) of the XVCO will be increased (approximately doubled) by the addition of a 0.5 μf capacitor in the loop filter selector, which results in a loop bandwidth increase from 750 to 1500 Hz.

d. Cooling air inlet to OA-7 will be blocked off, providing warmer air around the SDD.

3.6 RECEIVE AND RECORD SPACECRAFT VOICE; TRANSMIT VOICE

3.6.1 Test Result Summary

The A/RIA spacecraft voice links performed to expected values. The VHF voice subsystem produced a measured output SNR of 18 dB (average) at the specification signal input of 5.4 X 10^{-15} watts/m^2. The USB voice subsystem produced a measured output SNR of 20 dB (average) at the specification signal input of 2.3 X 10^{-14} watts/m^2 (total carrier power). The voice links were tested in various environments, including the Tulsa ground station, the C-121 Apollo Simulator, and Gemini. The operation of the uplink voice transmitters and the verification receivers was satisfactory. The functional reliability of the spacecraft voice system proved satisfactory.

3.6.2 VHF Tests Performed

Test 1 Receive and record uncombined and polarization combined VHF voice, at a signal power of 5.4 X 10^{-15} watts/m^2 (Reference A/RIA Tech Note A0143, Amendment B) from the ground station signal source (T. P. Paragraph 7.6.1. C. 2).

Test 2 Receive and record combined VHF voice and measure S+N to N at signal levels from -100 dBm to -115 dBm at the A/RIA directional coupler from the ground station signal source.

Test 3 Use of VHF for communications on all ground station flights.

Test 4 Receive and record VHF/USB combined voice at signal powers of 5.4×10^{-15} watts/m^2 for VHF and 2.3×10^{-14} watts/m^2 (A/RIA Tech Note A0143, and CP100002A) for USB from the ground station signal source (T. P. Paragraphs 7. 6. 1. C. 2, 7. 6. 2. C. 2).

Test 5 Receive and record VHF voice from the NASA C-121 aircraft (T. P. Paragraph 7. 6. 1. C. 2).

Test 6 Receive and record VHF/USB combined voice from the NASA C-121 aircraft (T. P. Paragraphs 7. 6. 1. C. 2, 7. 6. 2. C. 2).

Test 7 Transmit VHF voice at 296. 8 MHz to the ground station (T. P. Paragraph 7. 7. 1. C. 1).

Test 8 Transmit VHF voice at 296. 8 MHz to the NASA C-121 aircraft (T. P. Paragraph 7. 7. 1. C. 1).

Test 9 Receive and record VHF verification voice (T. P. Paragraph 7. 6. 2. C. 2).

3. 6. 3 VHF Test Environment

The VHF voice tests were performed in two environments, the Tulsa ground station and the NASA C-121 Apollo Simulator.

3. 6. 3. 1 Tulsa Ground Station

The VHF voice tests accomplished with the ground station were conducted under controlled conditions. Figure 65 and Figure 66 show the configurations used to accomplish all tests.

All signal levels radiated from the ground station were determined by link analysis only, since no AGC is available from the voice receiver. The ground station power levels were measured at the Antenna Patch Panel by use of the VHF variable attenuators and a HP 431B power meter.

Two techniques were used to derive confidence that the calculated levels were essentially correct:

a. The relationship of calculated versus measured signal powers for VHF telemetry was analyzed for these runs. Once general agreement on these was determined, it was assumed that the VHF voice link would show similar correlation.

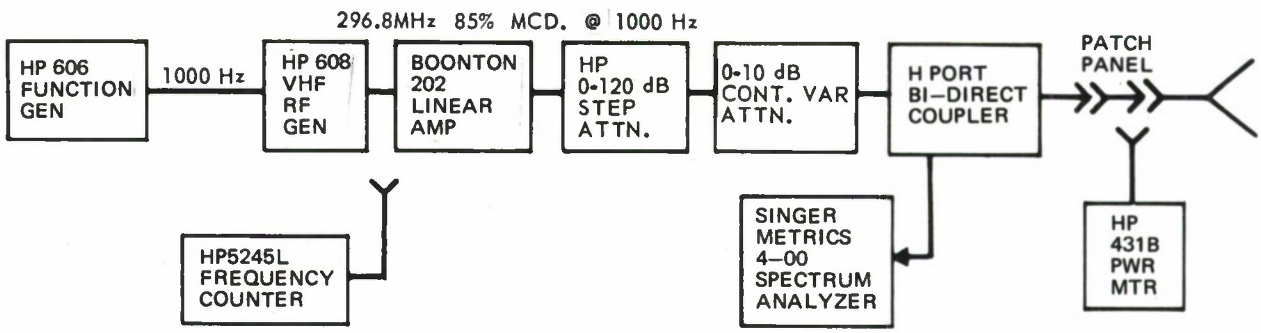


FIGURE 65. GROUND STATION CONFIGURATION MARGINAL LEVELS

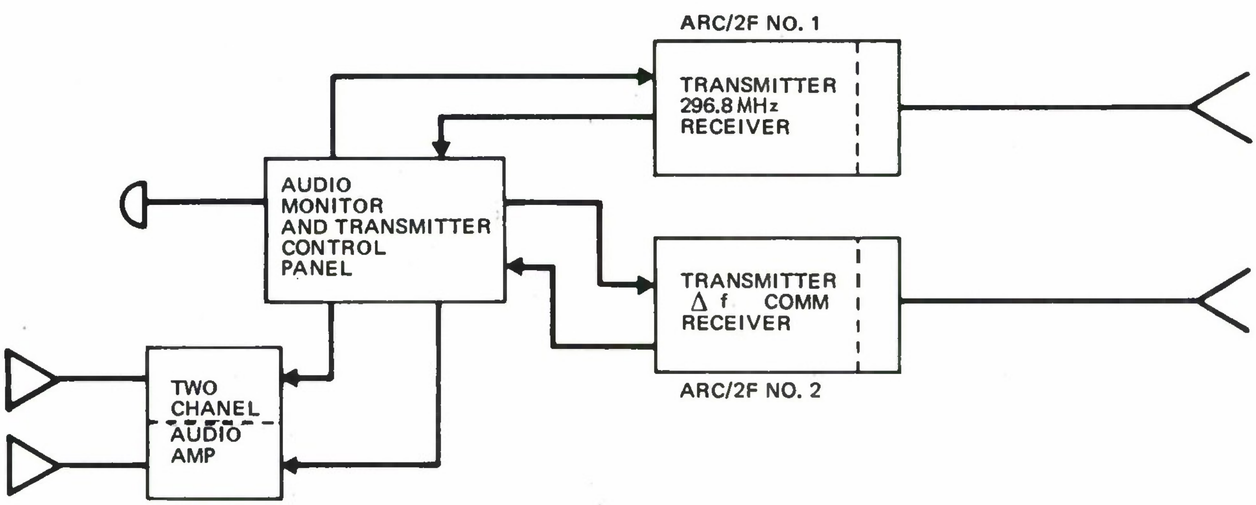


FIGURE 66. GROUND STATION CONFIGURATION FOR BASIC COMMUNICATIONS

b. The radiation pattern check signal strength time histories were compared against the recordings made during the runs used for the tests to insure that the pattern was essentially as predicted. Very little (less than 2 dB) variation was noted over the data interval.

Unfortunately, the VHF voice receive tests are actually less quantitative than the presentation of results may indicate. The primary variable, signal strength, is not recorded, and it is evident that output SNR's are a direct function of input power. The method of test implementation was the most scientific possible under the circumstances.

Figure 65 shows the ground station test setup used for tests at marginal levels (Tests 1, 2, and 4). The 608D signal generator was modulated 85 percent by a 1000-Hz tone from the 606 function generator. The 296.8-MHz AM signal from the 608D was amplified by the Boonton 202 linear amplifier and set to the required power levels at the patch panel.

For Test 3 (levels from -100 dBm down to -115 dBm at the directional coupler), the power level at the ground station patch panel was set to produce a signal level of -100 dBm at the A/RIA directional coupler. At Point 1 on the standard racetrack pattern (see Section 3. 1. 3, Flight Patterns), the VHF carrier was radiated without modulation. At Point 4 on the racetrack pattern, modulation was applied to the VHF signal. Subsequently, the modulation was turned on and off at 20-second intervals and the signal decreased in 3-dB steps down to -115 dB. Measurements were taken every 20 seconds.

All measurements necessary for tests were made between Points 4 and 5 of the standard racetrack pattern (see Section 3. 1. 3). Test equipment used to control test parameters was calibrated to Bendix Radio approved procedures.

Figure 66 shows the ground station test setup used for Tests 3 and 7 (basic communications). One ARC/27 transceiver, tuned to transmit and receive on 296. 8 MHz, was used to communicate between the ground station and the Mission Control Coordinator. The other ARC/27 was used for communication between the A/RIA Pilot/Test Engineer and the ground station. The ARC/27's were controlled from a remote control panel by the ground station operator.

3. 6. 3. 2 NASA C-121 Apollo Simulator

Tests 5, 6, 8, and 9 were accomplished by flying a predetermined flight pattern with the C-121 aircraft. All voice tests performed with the C-121 are qualitative only, since no 1000-Hz tone was used. Evaluation of voice quality and intelligibility was made by operator interviews and by playback of the audio recorder tapes.

3. 6. 4 VHF Data Collection Techniques

All SNR measurements were made and recorded by PMEE operators aboard the A/RIA aircraft. Uncombined voice measurements were made by the Telemetry Operator and combined voice readings taken by the HF Operator. Measurements were coordinated by the MCC for data reduction purposes. When required, the demodulated VHF voice signals were recorded on the audio recorder.

3. 6. 5 VHF System Configuration

The A/RIA PMEE configurations used to perform all voice tests are shown in Figures 67 and 68, receiving and transmitting, respectively.

The voice receiver IF bandwidth is shown as 30 KHz or 100 KHz. A 30-KHz IF bandwidth filter was not available until Flight 24; therefore, all VHF voice tests that were performed before that flight utilized a 100-KHz IF filter and the results were extrapolated for a 30-KHz IF bandwidth filter.

The VHF signals received at the A/RIA VHF antenna elements are passed by the appropriate VHF LHC and RHC diplexers and fed to the voice preamplifiers where they are amplified and passed to the appropriate VHF voice receiver channel. The VHF

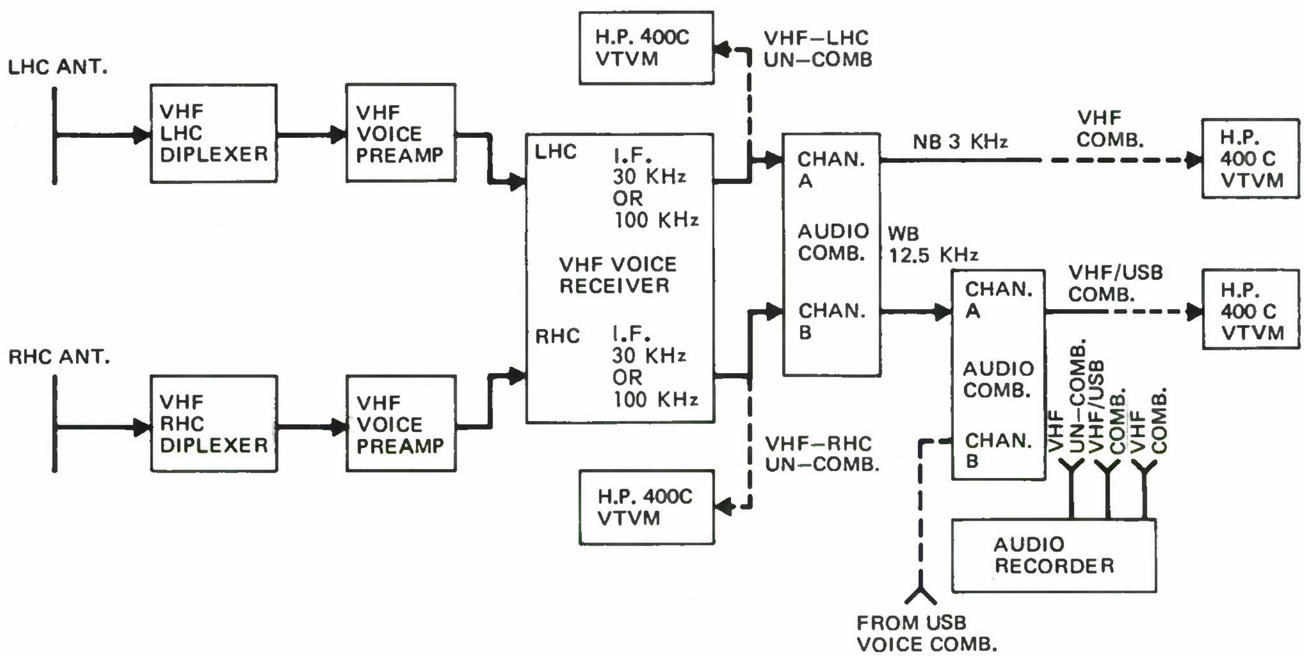


FIGURE 67. CONFIGURATION FOR VOICE TESTS, RECEIVING

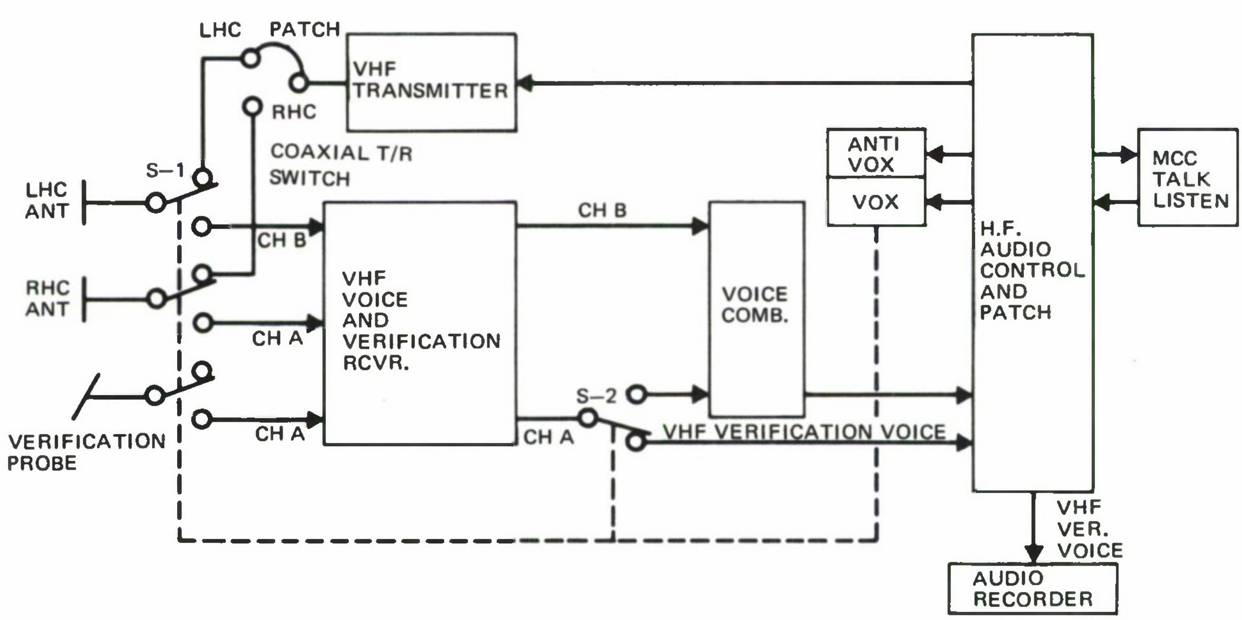


FIGURE 68. CONFIGURATION FOR VOICE TESTS, TRANSMITTING

AM composite signal is demodulated in the receiver and audio signals from the LHC and RHC channels are fed to the input of a voice combiner.

The voice combiner provides polarization diversity by sampling out-of-band noise and producing an output signal that is as good as or better than the best input signal. If one channel is inoperative, the combiner selects the other.

Another voice combiner is used to provide VHF/UHF combined audio signals by accepting the wideband (12.5 KHz) output of the VHF voice combiner and the wideband (12.5 KHz) output of the USB combiner. The voice combiners are provided with two outputs. A wideband output for driving another voice combiner or for other wideband applications, and a narrow-band (3 KHz) output for audio recording. The narrow-band (3 KHz) output of the combiner was used for all SNR measurements.

Figure 68 is a simplified block diagram of the VHF voice transmit and VHF voice verification equipment. The system is shown in the transmit mode, where relays S-1 (transmit/receive relay) and S-2 (verification relay) are energized. S-1 and S-2 are energized by the voice operated relay (VOX). The VOX is energized either by a signal from the uplink HF circuit or from the MCC position; only the MCC signal will be considered for tests covered in this section.

The MCC-originated signal activates the VOX, which in turn energizes S-1 and S-2. The audio signals from the MCC modulates the VHF transmitter and the VHF signal is transmitted by either the LHC or the RHC antenna elements; i.e., the transmitter is patched to only one channel. The VHF signal is sampled by the VHF verification probe and fed to one channel of the VHF voice receiver. The VHF receiver demodulates the signal and the audio output is sent into the HF Audio Patch Panel, where it can be patched into the audio recorder or monitored by the Voice Operator.

3.6.6 VHF System Performance

The A/RIA VHF voice subsystem performed to expected values. With the specification signal input of 5.4×10^{-15} watts/m^2, the average output SNR measured 18 dB. With input signals from 9.5×10^{-14} watts/m^2 to 3.1×10^{-15} watts/m^2, the output SNR measured between 11.5 dB and 25.5 dB. The VHF voice transmit and verification voice links performed as expected.

Voice quality and intelligibility were evaluated in accordance with the procedures recommended by J. C. R. Licklider and George A. Miller, in The Perception of Speech, Chapter 26, page 1049, Figure 11.

3.6.6.1 VHF System Performance —— Test 1

Receive and record uncombined and polarization-combined VHF voice at a signal power of 1.8×10^{-14} watts/m^2.

Specification

Intelligible voice at a power density of 5.4×10^{-15} watts/m^2.

Goal

With a power density level of 1.8 X 10^{-14} watts/m^2, a 100-KHz IF bandwidth and 3-KHz post-detection bandwidth, determine through test the output SNR and compare with the calculated theoretical value of +23.2 dB SNR.

Conditions

The specification power density of 5.4 X 10^{-15} watts/m^2 assumes a 30-KHz IF bandwidth filter in the voice receiver. Since a 30KHz filter was not available at the time that this test was performed, a 100-KHz filter was used. To insure adequate signal power in the IF with the wider filter, the signal was raised 5.2 dB above 5.4 X 10^{-15} watts/m^2 to 1.8 X 10^{-15} watts/m^2. It is recognized that for AM there is no predetection threshold requirement and that the output SNR is determined primarily by the post-detection bandwidth and the degree of modulation. For this reason, the calculated output SNR at the higher received signal power is 5.2 dB higher (23.2 dB) than that calculated at the specification power level of 5.4 X 10^{-14} watts/m^2 (18 dB).

VHF AM Voice Downlink

P_{dc} (Received signal power at directional coupler)	-107.0 dBm
Φ_{dc} (Noise spectral density at directional coupler 807°K)	-169.5 dBm/Hz
$(\frac{C}{N_1})$ dB = carrier CNR in 1-Hz bandwidth	+ 62.5 dB
Predetection noise bandwidth factor = -10 log 100,000	- 50.0 dB
Predetection SNR	+ 12.5 dB

Evaluation of Output SNR

$(\frac{C}{N_1})$ dB	+ 62.5 dB
Post-detection noise bandwidth = -10 log 2b	
(b = 3000 Hz)	- 37.8
10 log M^2 M = 0.85	- 1.4
Output SNR (Combiner improvement is not included in this calculation)	+ 23.3

The VHF uncombined (LHC and RHC) measurements were made at the 15-KHz video outputs of the voice receiver and the VHF combined measurements were made at the 3-KHz output of the voice combiner. Since the voice link has a post-detection bandwidth of 3 KHz, the readings taken at the 15-KHz bandwidth must be corrected to 3 KHz.

An improvement of 7.0 dB is realized by converting to a 3-KHz post-detection bandwidth.

Test Results

The test results are shown in Table XXXI.

NOTE

> The 12.5-KHz value is a front panel switch position, and corresponds to the bandwidth at 1 dB down. The bandwidth at the 3-dB point is 15 KHz.

As can be seen from Table XXXI, the calculated SNR values are consistently higher than the measured. These calculated values, however, are premised on deriving a noise spectral density using a 300°K temperature for the antenna. The 300°K figure was used in all link calculations defined in A/RIA technical notes and was based upon the A/RIA aircraft operating in a low ambient noise level environment, namely supporting an Apollo mission over the ocean. However, operating against a ground station in the Tulsa area presents a far different situation since it can be assumed that the ambient noise levels (man made) certainly exceed those expected over the ocean. For example, a Lincoln Laboratory Tech Note, No. 1966-59, entitled "Noise Temperature of Airborne Antennas at UHF" presents the following tabulation of noise temperatures recorded on a C-121 over Eastern U. S. cities. The operating frequency was 305.5 MHz:

City	Altitude	Temperature (°K) at 305.5 MHz
Boston	8 K	8000
Baltimore	18 K	7000
Jacksonville	14 K	3400
Miami (Cold)	18 K	4600
(Hot)	10K - 18K	10500
Orlando	9 K	4000
Philadelphia	8K - 18K	9000
Brooklyn	8K - 18K	19000
Manhattan	8K - 18K	30000

TABLE XXXI

VHF Voice SNR – Combined and Uncombined

Measurement Number	LHC		RHC		Uncombined	Combined**
	Measured in a 15 KHz Post-D B. W.	Corrected to a 3 KHz Post-D B. W.	Measured in a 15 KHz Post-D B. W.	Corrected to a 3 KHz Post-D B. W.	Uncombined SNR (Calculated)	Measured in a 3 KHz Post-D B. W.
Flt. 21 - #1	10. 0 dB	17. 0 dB	11. 0 dB	18. 0 dB	23. 3 dB	19 dB
Flt. 21 - #2	10. 0 dB	17. 0 dB	11. 0 dB	18. 0 dB	23. 3 dB	18 dB
Flt. 21 - #3	7. 0 dB*	14. 0 dB	10. 0 dB	17. 0 dB	23. 3 dB	17 dB
Flt. 21 - #4	10. 0 dB	17. 0 dB	11. 0 dB	18. 0 dB	23. 3 dB	18 dB
Flt. 22 - #5	10. 2 dB	17. 2 dB	11. 8 dB	18. 8 dB	23. 3 dB	18 dB
Flt. 22 - #6	10. 0 dB	17. 0 dB	11. 0 dB	18. 0 dB	23. 3 dB	17 dB

*It is assumed that this reading was made in error. At the same time, the RHC channel was reading 10 dB. Also, readings before and after this reading are as expected.

**Combiner improvement, typically up to 2 dB, cannot be predicted because of the method of taking measurements.

A special data run was performed on Flight 20 to establish the effects of man-made noise at VHF frequencies in the Tulsa area. The results showed an increase in system noise temperature of 3 dB to 4 dB when the antenna was varied from zenith to the antenna look-angles used during a routine data run.

In addition to the added system noise, a tolerance for received signal power and S+N/N measurement is applicable. Using the Root-Sum-Squared technique:

$$e_{RSS} = \pm \sqrt{(e_{po})^2 + (e_m)^2}$$

$$e_{RSS} = \pm \sqrt{(2)^2 + (2)^2}$$

$$e_{RSS} = \pm \; 2.8$$

where, e_{po} is the error in computing received signal power and e_m is the S+N/N measurement error. The measured S+N/N ratios fall within the established tolerance. The correction factor for comparing $\frac{S+N}{N}$ measurements to theoretical SNR is given by: $\frac{S+N}{N} - 1 = \text{SNR}$ (in power levels. This correction is insignificant at these high SNR's.

The conditions under which this test was run are not well enough controlled to indicate voice combiner action. The received signal level changes as the aircraft flew in the pattern caused the meter reading to change by 2 dB to 3 dB; the operator averaged this reading instinctively. The S+N/N readings for Channel 1 and Channel 2 were made sequentially by the same operator. Any discussion concerning combiner action would require that the two-channel S+N/N readings be simultaneous.

3.6.6.2 VHF System Performance —— Test 2

Receive and record VHF voice and measure SNR at signal levels from -100 dBm to -115 dBm at the A/RIA directional coupler.

Goal

Determine the SNR throughout expected range of signal input power.

Conditions

For these tests, a 30-KHz IF bandwidth filter was used and readings were taken through a 3-KHz post-detected output. The signal powers listed are calculated only, since no AGC is available from the VHF voice receiver. Based upon general agreement between VHF TLM computed versus measured values during the program, it has been determined that the computed values are satisfactory for these tests. A typical VHF voice link analysis follows:

VHF AM Voice Down Link

$-P_t$	(Transmitter power at Ground Station patch panel)	- 5.3 dBm
$-L_t$	(Loss between Ground Station patch panel and antenna)	- 2.7
$+G_t$	(Transmitting antenna gain)	+ 10.5
$-L_s$	(Space Loss for 70 nm at 296.8 MHz)	-124.2
$-L_p$	(Polarization loss)	- 4.1
$-L_y$	(Radome Loss)	- 0.3
$+G_y$	(Receiving antenna gain)	+ 13.0
$-L_u$	(Loss between receiving antenna and directional coupler)	- 1.9
P_{dc}	(Received signal power at A/RIA directional coupler)	-115.0 dBm
Φ_{kt}	(Noise spectral density at 831°K at directional coupler)*	-169.5 dBm
(C/N_1) dB, carrier = CNR in 1 Hz bandwidth		+ 54.5
Predetection noise bandwidth = -10 log 30 KHz		- 44.7
Predetection SNR		+ 9.7 dB

Calculation of Output SNR

(C/N_1) dB carrier	+ 54.5
Post detection noise bandwidth = $[-10 \log 2b]$; b = 3 KHz	- 37.8
$+10 \log (M^2)$ M = .85 (Reduction from 100% modulation)	- 1.4
Output SNR (Combiner improvement is not included in this calculation)	+ 15.3 dB

*See NOTE 1 following this section.

The link analysis is for the -115 dBm level only, however, the other levels may be computed in the following manner:

$$\text{Output SNR} = \left[(\Phi_{kt} - P_R) - (10 \log 2b) + (10 \log M^2)\right]$$

$$= \left[(169.5 - 100) - 37.8 + 1.4)\right]$$

$$= 69.5 - 39.2$$

$$\text{Output SNR} = 30.3$$

Test Results

The test results are shown in Table XXXII.

Combiner improvement, typically up to 2 dB, cannot be predicted because of the method of taking measurements.

The results of these tests show that the A/RIA will produce high SNR voice at input signals down to 3.1×10^{-15} watts/m^2 (-115 dBm). The 11.5-dB signal-to-noise ratio measured at -115 dBm proves that the VHF voice receive link is satisfactory for Apollo requirements.

The S+N readings, recorded during Flight 25, degraded considerably the SNR values because of low measured S+N levels. If the voice combiner balance control had been set up at 0 dBm on signal, the measured and calculated S+N to N ratios would have agreed very closely (the S+N/N would have been improved by 6 dB to 7 dB). The balance control was misadjusted by the operator. This balance, if misadjusted, has a significant effect on S+N, but a very minor effect on noise. It is not a gain control. The discussion given under Test 1 concerning the increase in system noise due to man-made noise and the measurement tolerances also applies to these data.

Voice quality and intelligibility were evaluated in accordance with the procedures recommended by J. C. R. Licklider and George A. Miller, in The Perception of Speech, Chapter 26, page 1049, Figure 11.

3.6.6.3 VHF System Performance —— Test 3

Use of VHF (296.8 MHz) for communications on all ground station flights.

Goal

Maintain intelligible two-way voice link.

TABLE XXXII

VHF Voice SNR Versus Input Power Level

Measurement No.	Measured			Calculated Signal Level at A/RIA Directional Coupler (dBm)	Calculated SNR (dB)
	S+N (dB)	N (dB)	S+N/N (dB)		
Flight 25					
1	-7	-26	19	-100	30.3
2	-6	-25	19	-103	27.3
3	-6	-23	17	-106	24.3
4	-6	-20	14	-109	21.3
5	-6.5	-17	10.5	-112	18.3
6	-7	-15	8	-115	15.3
Flight 31					
1	-2.5	-28	25.5	-100	30.3
2	-2.5	-26.5	24	-103	27.3
3	-2.5	-23.5	21	-106	24.3
4	-2.5	-20.5	18	-109	21.3
5	-3	-18	15	-112	18.3
6	-3.5	-15	11.5	-115	15.3

Test Results

The 296.8 MHz VHF AM voice link was used on all flights against the ground station for communications between the Ground Station operator and the Mission Control Coordinator aboard the A/RIA aircraft. By using the VHF AM voice link to control and coordinate the tests with the ground, the long-term reliability under a variety of conditions was proven. The VHF voice link proved to be extremely reliable. The only problems were caused by outside interference.

3.6.6.4 VHF System Performance —— Test 4

Receive and record VHF/USB combined voice at signal powers of 5.4×10^{-15} watts/m^2 for VHF and 2.4×10^{-14} watts/m^2 for USB.

Goal

Qualitative check only, record intelligible VHF/USB combined voice.

Conditions

A 100 KHz IF bandwidth filter was used in the VHF voice receiver because a 30 KHz IF bandwidth filter was not available. The radiated VHF level was raised to equalize the VHF and USB voice inputs, permitting the third combiner to operate on equal inputs.

Test Results

The values listed in Table XXXIII were measured during Flight 20.

The goal of intelligible VHF/USB combined voice was met. The USB SNR's shown are uncombined; the combined were likely higher, but were not measured. These combined measurements are taken by the HF operator. On a given data run, time will not permit taking VHF Combined, USB Combined and VHF/USB Combined readings. This test was not intended to be quantitative, even though the results are tabulated in measured SNR's. The test conditions and implementation lack the accuracy required to evaluate combiner action versus predicted improvement.

3.6.6.5 VHF System Performance —— Test 5

Receive and record VHF voice from the C-121 aircraft.

Specification/Goal

Record intelligible VHF voice.

TABLE XXXIII

VHF/USB Voice SNR, Combined and Uncombined

Measurement No.	USB Uncombined Measured in a 3 KHz Post-Detection Bandwidth (dB)		VHF Combined Measured in a 3 KHz Post-Detection Bandwidth (dB)	VHF/USB Combined Measured in a 3 KHz Post-Detection Bandwidth (dB)
	RHC	LHC		
1	19.8	19.8	22	22
2	19.8	19.8	22	22
3	19.8	19.8	22	22
4	19.8	19.8	22	21

Conditions

A/RIA flying against the C-121 as outlined in paragraph 3.1.3. A 30 KHz IF bandwidth filter was used in the VHF voice receiver, the narrow band (3 KHz) output of the VHF voice combiner was patched into the audio recorder. The C-121 voice output was .25 watts ERP, at a nominal range of 60-nm, resulting in a power density of 1.5 X 10^{-12} watts/m^2 at A/RIA.

Test Results

The audio recordings from Flights 13, 29, and 30 were played back and determined to be intelligible and of good quality.

3.6.6.6 VHF System Performance —— Test 6

Receive and record VHF/USB combined voice from the NASA C-121.

Goal

Intelligible voice recorded on the audio recorder.

Conditions

A/RIA flying against the C-121 as outlined in Section 3.1.3. A 30-KHz IF bandwidth filter was used in the VHF receiver. The USB track receivers were tuned to 2287.5 MHz. The C-121 transmitter modulations simulated transmissions from the Apollo CSM. Intelligible voice conversations were received and recorded.

Test Results

The audio recording from Flight 30 was played back and showed that the combined VHF/USB voice is intelligible.

3.6.6.7 VHF System Performance —— Test 7

Transmit VHF voice at 296.8 MHz to the ground station.

Goal/Specification

Transmit VHF voice at 100 watts. Received voice at ground station must be intelligible; verification voice must be intelligible.

Test Results

As discussed in Test 3, the VHF voice link was used for routine communications during each ground station test and operated satisfactorily. Further, the transmitter was used for voice relay to the Gemini. The verification voice was recorded on all flights.

Several audio tapes were played back and monitored by experienced voice communicators. The voice recordings were intelligible.

Simulation of an Apollo environment for voice transmission was not possible during the Category II test program. It was not within the scope of flight test. The primary A/RIA requirement, without an actual Apollo to receive the transmitted voice, is limited to a qualitative evaluation regarding A/RIA capability to transmit intelligible voice. This was successfully accomplished as outlined in this test and Test 8.

3.6.6.8 VHF System Performance —— Test 8

Transmit VHF voice at 296.8 MHz to the NASA C-121 aircraft.

Specification/Goal

Transmit 100 watts to the C-121. Received voice must be intelligible; verification voice must be intelligible.

Conditions

VHF voice transmitter power: 100 watts. Verification receiver patched to audio recorder. NASA C-121 configured to receive VHF voice at 296.8 MHz, 85 percent AM modulation.

Test Results

The 296.8 VHF AM voice link was used on all flights against the NASA C-121 for communications between the A/RIA Mission Control Coordinator and the C-121 Console Operator. Both the received voice aboard the C-121 and the recorded verification voice aboard the A/RIA were intelligible.

3.6.6.9 VHF System Performance —— Test 9

Receive and record VHF verification voice in the A/RIA aircraft.

Specification/Goal

Verification voice must be intelligible.

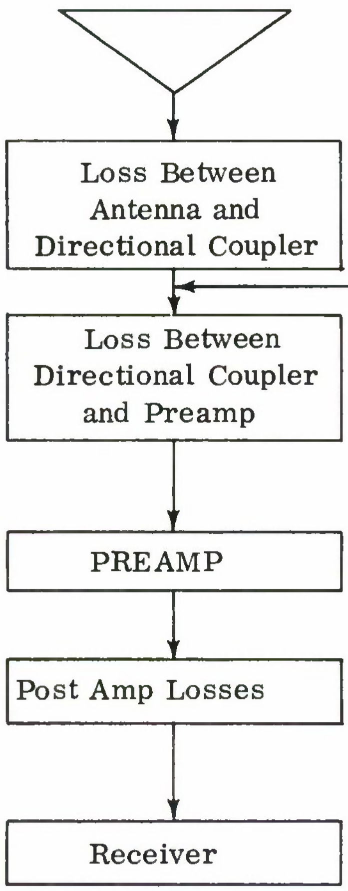
Test Results

VHF verification voice was recorded on all ground station and C-121 flights. Several audio tapes were played back and monitored (Flights 11, 13, 29, and 30). The VHF verification voice recordings were determined to be satisfactory. All recordings monitored were intelligible.

NOTE 1

VHF SYSTEM NOISE TEMPERATURE

CALCULATION REFERENCE TO DIRECTIONAL COUPLER



$T_A = 300^{\circ}K$

$L_1^1 = 2.0$ dB (1.584)

Reference Point for Noise Temperature T_{sys}, d.c.

$L_1 = 1.0$ dB (1.259)

$T_1 = 75^{\circ}K$

$G_1 = 22$ dB (158.2)

$NF_1 = 3.0$ dB, $T_2 = 290^{\circ}K$

$L_2 = 3.0$ dB (2.0)

$T_3 = 290^{\circ}K$

$NF_2 = 12$ dB, $T_4 = 4300^{\circ}K$

$$T_{sys},\ d.c. = \frac{T_A}{L_1^1} + \frac{(L_1^1 - 1)}{L_1^1} T_o + (L_1 - 1)\, T_o + (L_1\, T_2) + \frac{(L_1)}{G_1} T_3 + \frac{(L_1\, L_2)}{G_1} T_4$$

Where $T_o = 290^{\circ}K$ (See derivation)

$$T_{sys},\ d.c. = 189^{\circ} + 107^{\circ} + 75^{\circ} + 365^{\circ} + 2.3^{\circ} + 68.7^{\circ}$$

$$T_{sys},\ d.c. = 807^{\circ}$$

$$\phi_{KT} = 10 \log (1.38 \times 10^{-23} \times 807) = -199.5 \text{ dBW/Hz}$$

The system noise temperature and noise spectral density, referenced at the antenna, were computed in Tech Note A0140 (Page 6 of original issue, dated 6 April 1966) to be

$$T_{sys,\ ANT} = 1322^{o}K$$

$$I_{ANT} = -197.4 \text{ dBW/Hz}$$

The corresponding values when referenced at the directional coupler are

$$T_{sys,\ D.C.} = 807^{o}K$$

$$I_{D.C.} = -199.5 \text{ dBW/Hz}$$

It is seen that moving from the antenna to the directional coupler through the 2-dB loss, now designated as L_1^1, reduced the total system noise level by just 2 dB. Since the signal picked up by the antenna is also attenuated 2 dB in reaching this point, the signal-to-noise ratio is unchanged by changing the point of reference.

DERIVATION OF EXPRESSION FOR NOISE TEMPERATURE AT DIRECTIONAL COUPLER

Let T_o = Temperature of Loss Elements = 290^oK

$T_{sys,\ ANT}$ = System Noise Temperature referenced at Antenna

$T_{sys,\ D.C.}$ = System Noise Temperature referenced at Directional Coupler

$$T_{sys,\ ANT} = T_A + (L_1^1 L_1 - 1) T_o + (L_1^1 L_1) T_2 + \frac{(L_1^1 L_1)}{G_1} T_3 + \frac{(L_1^1 L_1 L_2)}{G_1} T_4$$

$$T_{sys,\ D.C.} = (T_{sys,\ ANT}) / L_1^1$$

$$= \frac{T_A}{L_1^1} + \frac{(L_1^1 L_1 - 1)}{L_1^1} T_o + (L_1 T_2) + \frac{(L_1)}{G_1} T_3 + \frac{(L_1 L_2)}{G_1} T_4$$

$$= \frac{T_A}{L_1^1} + L_1 T_o \quad \frac{1}{L_1^1} T_o + (L_1 T_2) + \frac{(L_1)}{G_1} T_3 + \frac{(L_1 L_2)}{G_1} T_4$$

$$= \frac{T_A}{L_1^1} + (L_1 - 1) T_o + (1 - \frac{1}{L_1^1}) T_o + (L_1 T_2) + \frac{(L_1)}{G_1} T_3 + \frac{(L_1 L_2)}{G_1} T_4$$

$$= \frac{T_A}{L_1^1} + \frac{(L_1^1 - 1)}{L_1^1} T_o + (L_1 - 1) T_o + (L_1 T_2) + \frac{(L_1)}{G_1} T_3 + \frac{(L_1 L_2)}{G_1} T_4$$

3.6.7 USB Voice Tests Performed

Test 1 Receive and record uncombined and polarization combined USB voice at a signal power of 2.4 X 10^{-14} watts/m^2 from the ground station signal source. (Reference CP 100002 and T. P. Paragraph 7.6.2.C.2)

Test 2 Receive and record USB voice from the NASA C-121 aircraft (Reference TP Paragraph 7.6.2.C.2).

Test 3 Lockup USB transponder, transmit USB voice at 2106.4 MHz to the NASA C-121 aircraft. (Reference T. P. Paragraph 7.7.2.C.3)

Test 4 Lockup USB transponder, transmit USB voice at 2106.4 MHz to the ground station, for evaluation of lockup stability.

Test 5 Receive and record USB verification voice. (Reference T. P. Paragraph 7.6.2.C.2)

Test 6 Receive and record USB emergency voice/1000 Hz tone.

3.6.8 USB Test Environment

The USB voice tests were performed in two environments, the Tulsa ground station, and the NASA C-121 Apollo Simulator.

3.6.8.1 Tulsa Ground Station

The USB voice tests accomplished with the ground station were conducted under controlled conditions. Figures 69, 70, and 71 show the configurations used to accomplish all USB voice tests.

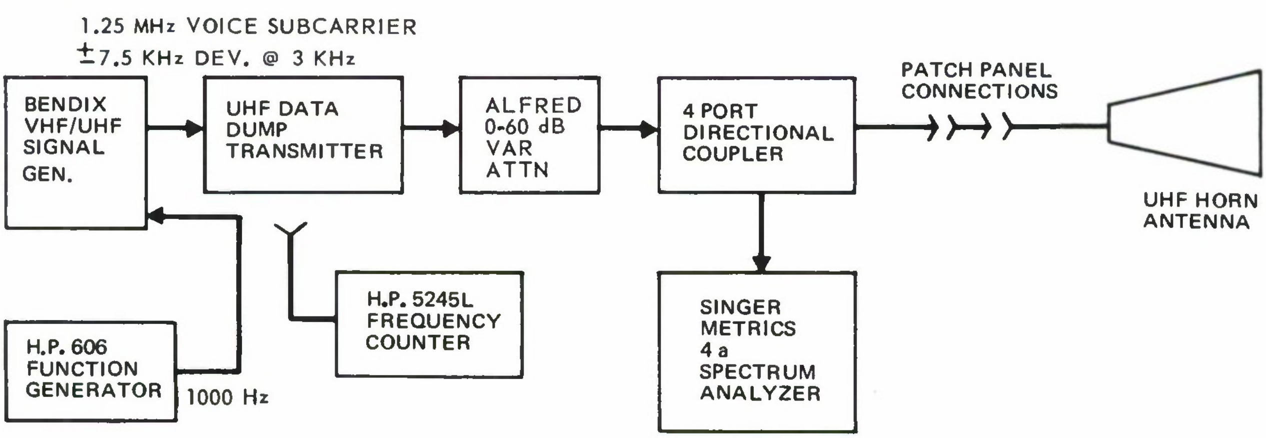


FIGURE 69. USB VOICE TESTS USING DATA DUMP TRANSMITTER

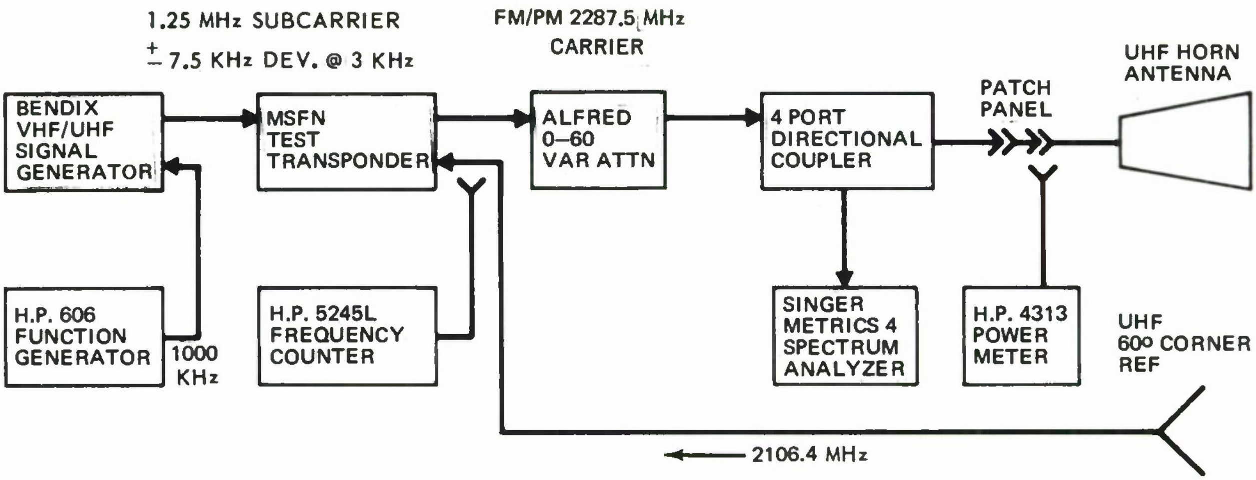
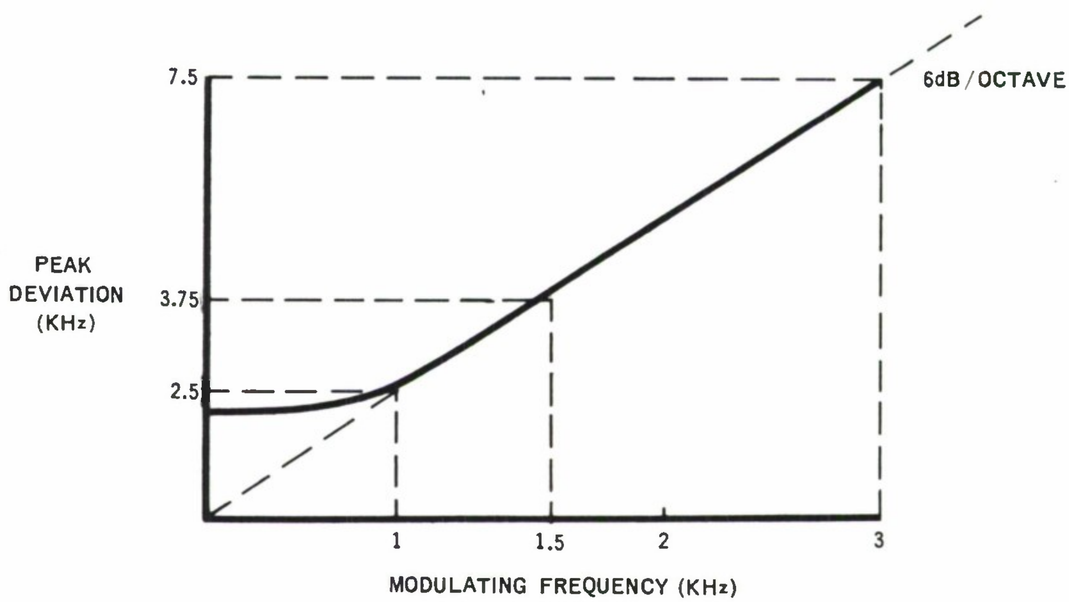


FIGURE 70. USB VOICE TESTS USING TRANSPONDER

Link analyses were performed to derive the ground station power output required for each desired A/RIA receive signal. The power levels were referenced to the ground station patch panel and set by use of the Alfred variable attenuator and the HP 431B power meter.

Figure 69 shows the ground station configuration used for Tests 1 and 2. A 1000-Hz tone from the HP 606 function generator was fed into the 1.25-MHz FM voice subcarrier modulator input; the 1000-Hz tone deviated the 1.25-MHz subcarrier ±2.5 KHz. The modulation characteristics for the USB voice subcarrier include a voice bandwidth of 300 to 3000 Hz, a peak deviation of 7.5 KHz and a pre-emphasis of 6 dB/octave. A sketch of modulating frequency versus subcarrier deviation is shown below.



The peak deviation of 7. 5 KHz must occur at a modulating frequency of 3 KHz and a break in the pre-emphasis is assumed to occur at 800 Hz. The peak deviation for low modulating frequencies approaches 2. 25 KHz in the low-frequency limit. The sketch above is applicable only for a constant baseband amplitude input to the pre-emphasis network and modulating circuitry. The A/RIA USB voice subcarrier demodulator utilizes a complementary de-emphasis network matched to the modulation characteristics of the sketch.

From the above discussion, it is evident that a $\pm$7. 5-KHz deviation and the FM improvement resulting from this deviation will only occur with a 3-KHz modulating frequency. The 1-KHz tone used for these tests yielded a 2. 5-KHz subcarrier deviation, as indicated in the sketch. The FM-modulated subcarrier phase modulates the 2287. 5-MHz carrier of the data dump transmitter by a specified amount depending on the data bit rate. (0. 54 radian at 51 2 KBPS and 0. 84 radian at 1. 6 KBPS.) The output signal power of the data dump transmitter was set to the required level at the patch panel.

Figure 70 shows the ground station test setup used for Test 5, where the MSFN USB test transponder was used for transmitting and receiving the USB signals.

The 1000 Hz tone from the HP 606 generator was set to deviate the 1. 25-MHz subcarrier $\pm$2. 5 KHz; the 1. 25-MHz FM voice subcarrier phase modulated the 2287. 5-MHz transponder carrier a specified amount depending on the PCM bit rate. (. 54 radians at 51. 2 KBPS and . 84 radians at 1. 6 KBPS) The output signal of the transponder was set to the required power level at the patch panel.

The A/RIA aircraft transmitted to the ground station on 2106. 4 MHz and phase locked the transponder by automatic and manual sweep modes. A sweep period of 15 seconds was used for automatic sweep.

All measurements necessary for tests were made between Points 4 and 5 of the standard racetrack pattern (see Section 3. 1. 3). Test equipment used to control test parameters had current calibrations at all times.

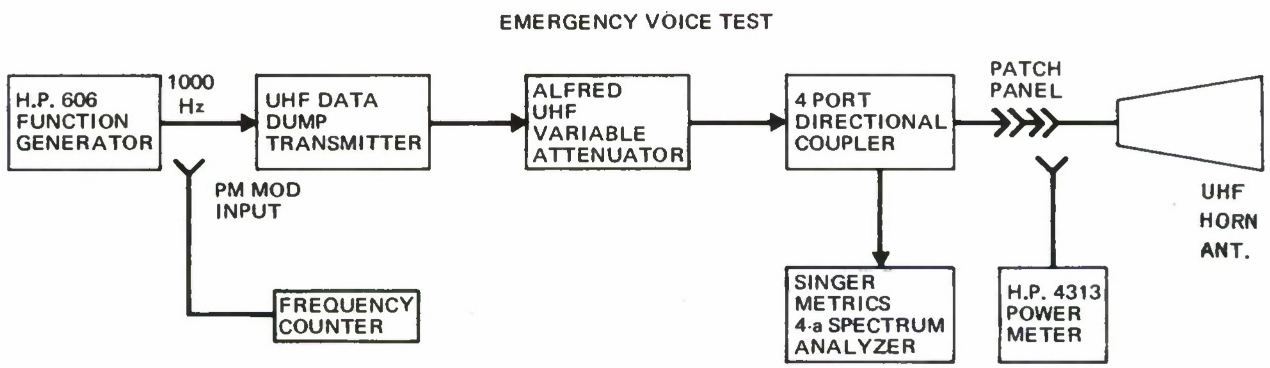


FIGURE 71. EMERGENCY VOICE TEST

Figure 71 shows the ground station test setup used for Test 7. A 1000-Hz tone from the HP 606 function generator was used to phase modulate the 2287.5-MHz carrier of the UHF data dump transmitter. The output power of the data dump transmitter was set at the patch panel by use of the Alfred variable attenuator and the HP 431B power meter.

3.6.8.2 NASA C-121 Apollo Simulator

Tests 3 and 4 were accomplished by flying the predetermined flight pattern (see paragraph 3.1.3) with the C-121 aircraft. The USB voice tests performed were similar to those performed against the ground station, with these exceptions:

a. The C-121 could demodulate the USB voice.

b. The USB voice link was used for communications during all Category II flights (6, 13, 29, and 30).

c. The C-121 provided a dynamic signal environment.

3.6.9 Data Collection Techniques

All SNR measurements were made and recorded by PMEE operators aboard the A/RIA aircraft. Voice uncombined measurements were made by the Voice Operator and voice combined readings taken by the HF Operator. Measurements were coordinated by the MCC for data reduction purposes. When required, the demodulated USB voice signals were recorded on the audio recorder.

3.6.10 UHF System Configuration

The A/RIA PMEE configurations used to perform all tests are shown in Figures 72 and 73. Figure 72 is the receiving configuration and Figure 73 is the transmitting configuration of the USB voice system.

The signals received by the RHC and LHC elements of the UHF antenna are amplified by the appropriate parametric amplifier and the traveling wave tube amplifier and fed to the tracking/data receivers.

The 3.3-MHz IF outputs of the receivers are fed to the signal data demodulators for processing. The demodulated audio outputs (11 KHz BW) of the two signal data demodulator units are connected into the voice combiner. The voice combiner provides polarization diversity by sampling out-of-band noise and producing an output that is as good as, or better than, the best input signal. The voice combiners each have two outputs, a wideband output (12.5 KHz) for driving another voice combiner, and a narrow-band output (3 KHz) for audio recording.

The narrow-band (3 KHz) outputs were used for all voice-combined SNR measurements.

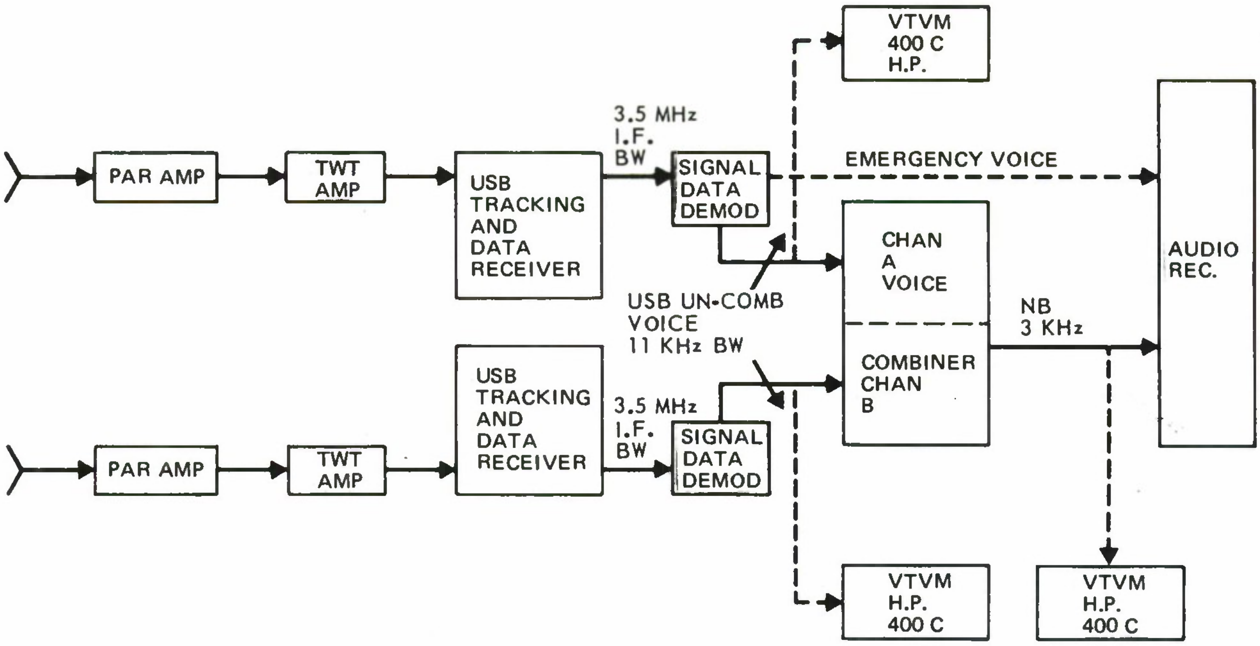


FIGURE 72. PMEE CONFIGURATION FOR USB VOICE, RECEIVING

The voice uncombined measurements were made at the 11-KHz bandwidth outputs of the signal data demodulators.

Figure 73 is a simplified block diagram of the USB transmitting and verification receiver system. The system is shown with Transmitter 1 modulated by audio from the MCC position and transmitting through the diplexer into the LHC antenna element. The composite UHF signal is sampled by the UHF verification probe and fed to the UHF verification receiver. The receiver demodulates the signal and the audio output is sent to the HF patch panel, patched into the audio recorder or to the Voice Operator.

The transmitter sweep circuits are used for transponder lockup. The sweep may be operated manually or automatically. In Figure 73 the sweep circuits are shown in the automatic mode. The transmitter carrier frequency sweeps plus and minus 300 KHz every 5, 15, 25, or 35 seconds as selected by the transmitter sweep period selector switch on the transmitter control Panel.

Transponder lockup occurs when the transmit and receive frequencies begin sweeping together.

Transmitter 2 is shown patched into the dummy load on standby status.

3.6.11 <u>UHF System Performance</u>

The A/RIA USB voice subsystem performed to expected values. With the specification signal input of 2.4 X 10^{-14} watts/m^2, the output SNR measured 20 dB. USB voice

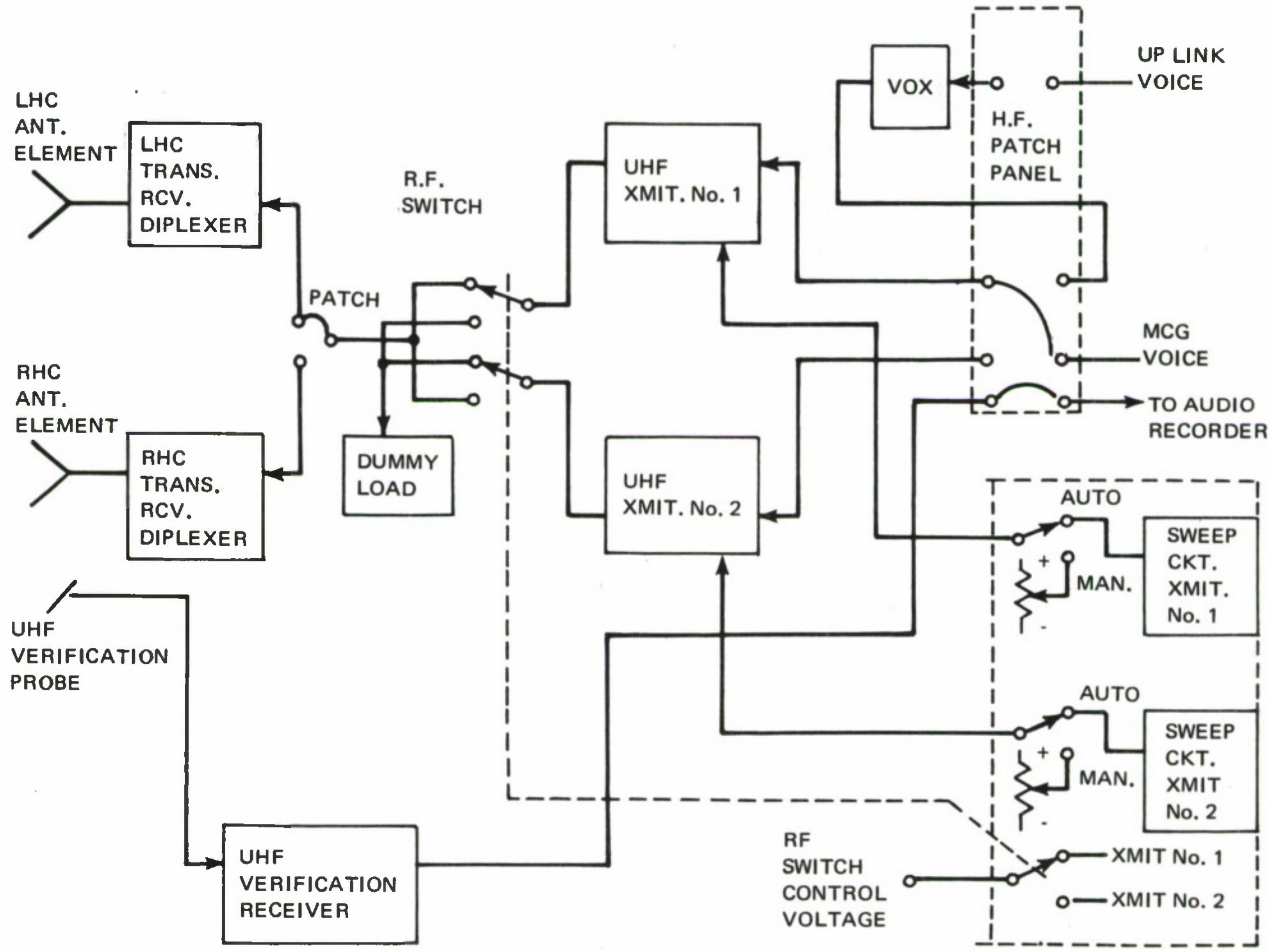


FIGURE 73. PMEE CONFIGURATION FOR USB VOICE, TRANSMITTING

communications were satisfactorily conducted, and USB transponder lockup was accomplished successfully with very few exceptions.

3.6.11.1 UHF System Performance —— Test 1

Receive and record uncombined and polarization combined USB voice at a signal power of 2.4 X 10^{-14} watts/m^2.

Specification

Intelligible voice at 2.4 X 10^{-14} watts/m^2 receive power level.

Goal

With a power density level of 2.4 X 10^{-14} watts/m^2 (-105.5 dBm at A/RIA directional coupler) determine through test the output SNR and compare with the calculated theoretical value of +18.7 dB.

Conditions

The post detection bandwidth at the point where the USB uncombined measurements were made was 11 KHz and the bandwidth at the point where the combined measurements were made was 3 KHz. An improvement of 5.6 dB is realized by converting from the 11-KHz to the 3-KHz bandwidth.

The link analysis derived for this test was as follows:

USB Voice Subcarrier

P_t (Transmitter power at ground station patch panel)	+ 1.5
$-L_t$ (Loss between patch panel and antenna)	- 5.1
G_t (Transmitting antenna gain)	+ 16.2
$-L_s$ (Space loss for 2287.5 MHz at 70-nm)	-141.9
$-L_p$ (Polarozation loss, circular to linear)	- 4.1
$-L_y$ (Radome loss)	- 0.7
G_T (Receiving antenna gain)	+ 30.6
$-Pr$ (Received signal at A/RIA antenna)	-103.5 dBm
$-L_m$(Subcarrier modulation loss)	- 11.5 dB
Φ_{KT} (Spectral noise density: 1069°K, T_A = 103°K)	-168.3 dBm
(S/N_1) dB Voice Subcarrier = $(\Phi_{KT} - Pr)$	+ 53.3 dB

Predetection SNR Calculations

(S/N_1) dB Voice Subcarrier	+ 53.3
Phase lock loop noise bandwidth = $(-10 \log 2b_{1_0})$ b=10 KHz	- 43.0
Predetection SNR	+ 10.3

Output SNR Calculation

(S/N_1) dB Voice Subcarrier	+ 53.3
Post-detection noise bandwidth = (-10 log 2b) b = 3 KHz	- 37.8
FM Improvement 10 log $\left[3\left(\frac{\Delta F}{b}\right)^2\right]$, $\Delta F = 2.5$ KHz for 1000 Hz modulation	+ 3.2
Output SNR	+ 18.7 dB

Test Results

The test results are shown in Table XXXIV.

The USB received signal for this run was measured to be approximately -106 dBm at the A/RIA directional coupler, or 2.4×10^{-14} watts/m^2 at the antenna. An AGC calibration was performed both before and after the run. Since USB voice is FM, the FM threshold loss must be considered in deriving the SNR spread corresponding to the 2-dB tolerance on received signal level. The 2-dB tolerance on signal strength was established by analyzing AGC readings over a period of several months. The tolerance represents the composite average of short and long-term signal level and measurement fluctuations. Over the range of measurements the predicted, preflight and inflight values normally remained within the tolerance band. Referring to link analysis above, a change in predetection SNR from 10.3 dB to 8.3 dB or 12.3 dB will result in an output SNR change from 18.7 dB down to 11.6 dB or up to 20.7 dB. The tolerance on output SNR thus becomes +2.0, -7.1. Allowing a 2-dB S+N/N measurement error (the meter needle swings this amount), the tolerance becomes:

$$e_{RSS} = -\sqrt{(e_{po})^2 + (e_m)^2} \qquad e_{RSS} = +\sqrt{(e_{po})^2 + (e_m)^2}$$

$$e_{RSS} = -\sqrt{(7.1)^2 + (2)^2} \qquad e_{RSS} = +\sqrt{(2.0)^2 + (2)^2}$$

$$e_{RSS} = -\ 7.4 \text{ dB} \qquad e_{RSS} = +\ 2.8 \text{ dB}$$

The output SNR tolerance for this test is, therefore:

$$18.7 \begin{matrix} +2.8 \\ -7.4 \end{matrix} = 11.3 \text{ dB to } 21.5 \text{ dB}$$

The ten measurements taken (five at RHC and five at LHC) were within $\approx$ 1 dB of the calculated value of 18.7 dB. The combiner improvement shown in Table XXXIV is not indicative of the theoretical improvement possible. The SNR measurements were not made simultaneously on both channels, making quantitative combiner evaluation impossible.

TABLE XXXIV

UHF Voice SNR, Combined and Uncombined

Measurement	LHC Measured in a 11 KHz Post-Detection Bandwidth	LHC Corrected to a 3 KHz Post-Detection Bandwidth	RHC Measured in a 11 KHz Post-Detection Bandwidth	RHC Corrected to a 3 KHz Post-Detection Bandwidth	Combined Measured in a 3 KHz Post-Detection Bandwidth
1	14	19.6	14	19.6	21
2	14	19.6	14	19.6	21
3	13	18.6	14	19.6	21
4	13	18.6	14	19.6	21
5	13	18.6	14	19.6	21
6	8	13.6	12	17.6	20
7	8	13.6	12	17.6	20
8	8	13.6	13	18.6	20
9	9	14.6	13	18.6	20
10	9	14.6	13	18.6	20

A second run was made to establish repeatability of data. The measured signal power was the same. The results are shown in Table XXXIV. On this run, the LHC readings show some degradation; no specific cause was ascertained. A meter reading error on LHC is likely, however, since the combined output measured very close to the test presented earlier. Also, the combined values show an improvement over the RHC uncombined; the amount of improvement indicates that the two combiner inputs were substantially the same SNR.

3.6.11.2 UHF System Performance —— Test 2

Receive and record USB voice from the NASA C-121 aircraft.

Specification/Goal

Receive and record intelligible voice.

Conditions

The USB voice link was established by locking up the transponder aboard the C-121 aircraft, the NB (3 KHz) output of the voice combiner was patched into the audio recorder. The received signal power at A/RIA ranged from 1.1 X 10^{-13} watts/m^2 to threshold.

Test Results

The audio recordings from Flights 13, 29, and 30 were played back and evaluated by an experienced voice communicator. The voice is intelligible and of good quality.

3.6.11.3 UHF System Performance —— Test 3

Lock up USB transponder, transmit USB voice at 2106.4 MHz to the NASA C-121 aircraft.

Specification/Goal

Transmit USB voice at 100W; received voice at the C-121 must be intelligible; verification voice aboard A/RIA must be intelligible.

Conditions

A normal Apollo configuration USB voice link was established by locking up the USB transponder aboard the C-121 aircraft after a stable Autotrack on UHF. The range to the C-121 was approximately 60 nautical miles.

Test Results

During Flights 13, 29, and 30 the received voice aboard the C-121 and the verification voice aboard the A/RIA aircraft were monitored and both the receive and verification voices were intelligible.

Transponder lockup was attempted and maintained on all flights. Since no instrumentation is available to monitor transponder lock, it is difficult to ascertain the cause of the relatively few unlocks recorded in the operators' logs. It has been conclusively determined, however, on all C-121 flights and several ground station flights, that transponder lock can be accomplished quickly and reliably. The lockup invariably occurs on the first half of the first 15-second sweep period (less than 7. 5 seconds).

3. 6. 11. 4 UHF System Performance —— Test 4

Lockup USB transponder, transmit USB voice at 2106. 4 MHz to the ground station for evaluation of lockup stability.

Specification/Goal

Evaluate transponder lock stability while tracking USB and VHF.

Conditions

A normal Apollo configuration transponder lockup was accomplished with the USB test transponder in the A/RIA ground station. The transponder AGC meter was used to monitor lock. The transponder transmitted on 2287. 5 MHz and received on 2106. 4 MHz. The aircraft flew the standard racetrack pattern. The A/RIA UHF transmitter power output was 100 watts, and the transmitter was operated in automatic sweep mode (sweep period was 15 seconds).

Test Results

The MSFN test transponder was monitored for lock stability on Flights 24, 25, and 31. The tests were very satisfactory.

The Voice and Tracking Operators aboard the A/RIA aircraft experienced no difficulty in locking up the transponder and once the unit was locked up a stable link was maintained. Both telemetry and voice data (a 1000-Hz tone) were used to modulate the transponder and the data looked good as reported by trained observers aboard the A/RIA aircraft.

3. 6. 11. 5 UHF System Performance —— Test 5

Receive and record USB verification voice.

Specification/Goal

Verification voice must be intelligible.

Conditions

Normal configuration, USB verification voice patched to the audio recorder.

Test Results

The audio recordings from Flights 13, 29, and 30 were played back and monitored by an experienced voice communicator. The verification voice was intelligible.

3.6.11.6 UHF System Performance —— Test 6

Receive and record USB emergency voice modulated with a 1000-Hz tone.

Specification/Goal

Qualitative evaluation of received tone.

Conditions

The ground station UHF data dump transmitter 2287.5-MHz carrier was phase-modulated by a 1000-Hz tone from the HP 606 function generator and radiated via the UHF horn antenna. The normal USB subcarriers were not used. The A/RIA signal data demodulator emergency voice output was patched to the audio recorder.

Test Results

An emergency voice test was made during Flight 22; the demodulated signal was recorded and monitored aboard the A/RIA aircraft. The tone was free of distortion.

3.6.12 Functional Reliability/Operability

No equipment failures compromised voice tests during the program; however, one voice test was unsuccessful because of operator error. On Flight 20, Data Run 1, the VHF voice receiver was tuned off-frequency.

During the earlier flights of the Category II Test Program, a lack of some technical manuals and ground station test equipment made test control difficult. As a result, receiver output levels, SDD output levels and recorder input levels aboard A/RIA aircraft were not set to optimum values. Also, the ground station did not have a spectrum analyzer before Flight 10; this was required to set deviations and monitor spurious radiations. A 431B power meter was first acquired for Flight 10, making accurate output power measurements possible.

3.6.13 Design/Operational Problems

3.6.13.1 No Means for Recording VHF Voice Receiver AGC's

Problem

During Category II tests, VHF voice receiver signal strength could not be recorded on the oscillograph or on the wideband recorder. All readings were taken manually from AGC meters and compared to computed values, since the voice receiver AGC is not brought out to the RF patch. It may also be desirable to record this AGC during an Apollo mission, although it is not required.

Recommendations

It is recommended that an improvement change be proposed to cable the VHF voice receiver AGC to the RF patch panel, and provide jacks for patching the RHC and LHC voice into the data multiplexer.

3.6.13.2 No Parallel Jacks on RF Patch Panel

Problem

During Category II, many desired tests were either not possible or made very difficult because no parallel/monitor jacks are provided on the RF patch panels. The VHF and USB uncombined voice signals were not recorded because the signal outputs are not available when the voice combiners are patched to the receiver outputs. Also telemetry data outputs could not be patched to both wideband recorders simultaneously.

Recommendation

It is recommended that an improvement change be proposed to provide parallel jacks on the RF patch panels.

3.6.13.3 No Means of Disconnecting the Antenna During AGC Calibrations In Flight

Problem

During the Category II Test Program, AGC calibration had to be made with the antenna connected into the system. Because of this, the system was susceptible to external noise during calibration. On several occasions calibration was almost impossible because of radio frequency interference.

An example of this problem occurred during the missile shot. The AGC calibrations were performed as close in time as possible to the predicted acquisition. The calibrations were just completed in time for the missile commitment because of excessive interference on all tracking and data frequencies. This condition was aggravated because the Navigator required the APN-59 radar system for navigational purposes, and

the A/RIA tracking antenna had to be put into the stow position where the interference was the worst.

Recommendation

One solution to this problem would be to add a coaxial relay or a solid state switch into the system that would provide a means of disconnecting the antenna during calibrations. This solution is not recommended since it would increase system noise temperature through additional insertion loss.

3.6.13.4 Wideband Recorder Level Settings Difficult to Make

Problem

During the Category II tests, data was degraded on several occasions because the wideband recorder record levels were not set up correctly.

Recommendation

It is recommended that a VTVM and oscillator be provided in the Record Section to provide a means of calibrating the VU meters on the inputs of the record channels and a means of presetting record levels. This recommendation is proposed in ECP 55.

3.6.13.5 Excessive WOW and Flutter, Low SNR on Pemco Audio Recorder

During the Category II test, considerable data recorded with the Pemco recorder was of poor quality because of excessive WOW and flutter and a poor SNR. This problem is being investigated by the manufacturer and Bendix Radio. Bendix has designed a 300 Hz to 3 KHz, 18 dB per octave bandpass filter that will be installed in the audio coupler. Tests run at Bendix Radio indicate that this filter will improve the S+N to N by 12 dB. The manufacturer has stated that he has located and corrected a grounding problem and is presently modifying all of the recorders.

3.6.13.6 High Noise on VHF Voice Receive Link When Not Receiving Carrier

Problem

A high noise level exists on the VHF voice receive link when carrier is not being received.

Recommendation

It is recommended that ECP 57 squelch modification be approved.

3.7 VOICE RELAY

Test Result Summary

The A/RIA voice relay system performed as expected, once optimum operating techniques were developed. Downlink and uplink voice were relayed in various environments, including the A/RIA ground station (Tulsa), Douglas Dog (Tulsa), Fisher I (Cape), C-121 Apollo Simulator, Gemini, and A/RIA 375, located on the ground at Tulsa. The Gemini voice relays are not included herein, but are discussed in Section 3.12.1 (Gemini Coverage). The Gemini voice relays were not specific Category II tests. Intelligible voice was relayed uplink and downlink in all modes, and no interference was detected when teletype was sent during the voice relays. The functional reliability of the voice relay system was very satisfactory.

3.7.1 Tests Performed

Test 1 Relay combined VHF voice downlink to ground on HF (T. P. 7.8.1.C.1), and relay HF voice uplink by VHF (T. P. 7.8.1.C.2).

Test 2 Relay combined USB voice downlink to ground on HF, lockup transponder (T. P. 7.8.2.C.1), and relay HF voice uplink by USB, lockup transponder (T. P. 7.8.2.C.2).

Test 3 Special Voice Relay. Relay combined VHF voice downlink by HF (T. P. 7.8.3.C.1), and HF voice uplink by VHF (T. P. 7.8.3.C.2), using prerecorded tape for voice source and record received voice.

Test 4 Demonstrate that no RFI precludes transmitting and receiving TTY while relaying voice.

3.7.2 Test Environment (Signal Sources)

3.7.2.1 Douglas Dog HF Station

The Douglas Dog HF station operated simplex with an ARC-65, and duplex with an ARC-65 as a receiver, and a Collins type 30K, Model 5, as a transmitter.

3.7.2.2 A/RIA VHF/UHF Ground Station

The A/RIA ground station, simulating the spacecraft, transmitted and received VHF with an ARC-27. A tape recorder was used in conjunction with the ARC-27 for the special voice relay (see Figure 74).

3.7.2.3 AFETR HF Station

Fisher I HF at Cape Kennedy served as a source or terminal on several voice relays, operating duplex.

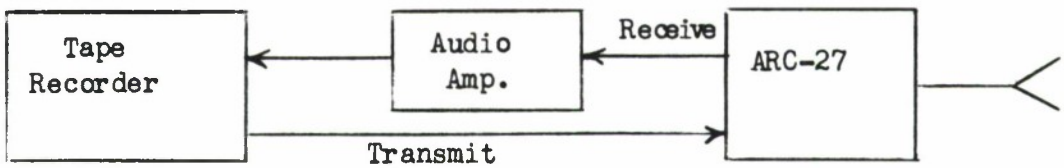


FIGURE 74. GROUND STATION SPECIAL VOICE RELAY BLOCK DIAGRAM

3.7.2.4 C-121 Apollo Simulator

The C-121 aircraft was used for several voice relay tests. Flight patterns were as per Section 3.1.3. USB voice was transmitted and received with an Apollo CSM transponder, and VHF voice was transmitted and received by an Apollo VHF voice transceiver.

An A/RIA aircraft, located on the ground at Tulsa, was the principle HF station used when voice relay and teletype were run simultaneously. The ground-based A/RIA was used exclusively for relays using prerecorded tapes.

3.7.3 Data Collection Techniques

Sources of data for the voice relay tests were completed flight cards or operators' logs, flight de-briefings, ground station logs, tape recordings made during the voice relays, and interviews with the A/RIA operators. The prerecorded tapes and tape recordings cut on the ground during the special voice relays are available and will be submitted upon request.

3.7.4 System Configuration

The Voice Relay Block Diagram shows the uplink and downlink paths through the A/RIA system. Communications between A/RIA and the ground is via HF (duplex), and between A/RIA and the spacecraft is via VHF (simplex) or USB (duplex). Three downlink voice relay configurations are available, VHF-HF, USB-HF, and VHF/USB-HF (see Figure 75).

3.7.4.1 VHF Downlink

For VHF-HF downlink, VHF is received by the VHF LHC and RHC antenna elements and passed to the voice receiver. The voice receiver detects the signals and feeds them to the voice combiner. The signals at the combiner have a bandwidth of 12.5 KHz, being a combination of audio and out-of-band noise. The combiner accepts the LHC and RHC outputs of the VHF voice receiver and supplies a composite output with a SNR equal to or better than the best input signal. The combiner outputs consists of combined audio and out-of-band noise.

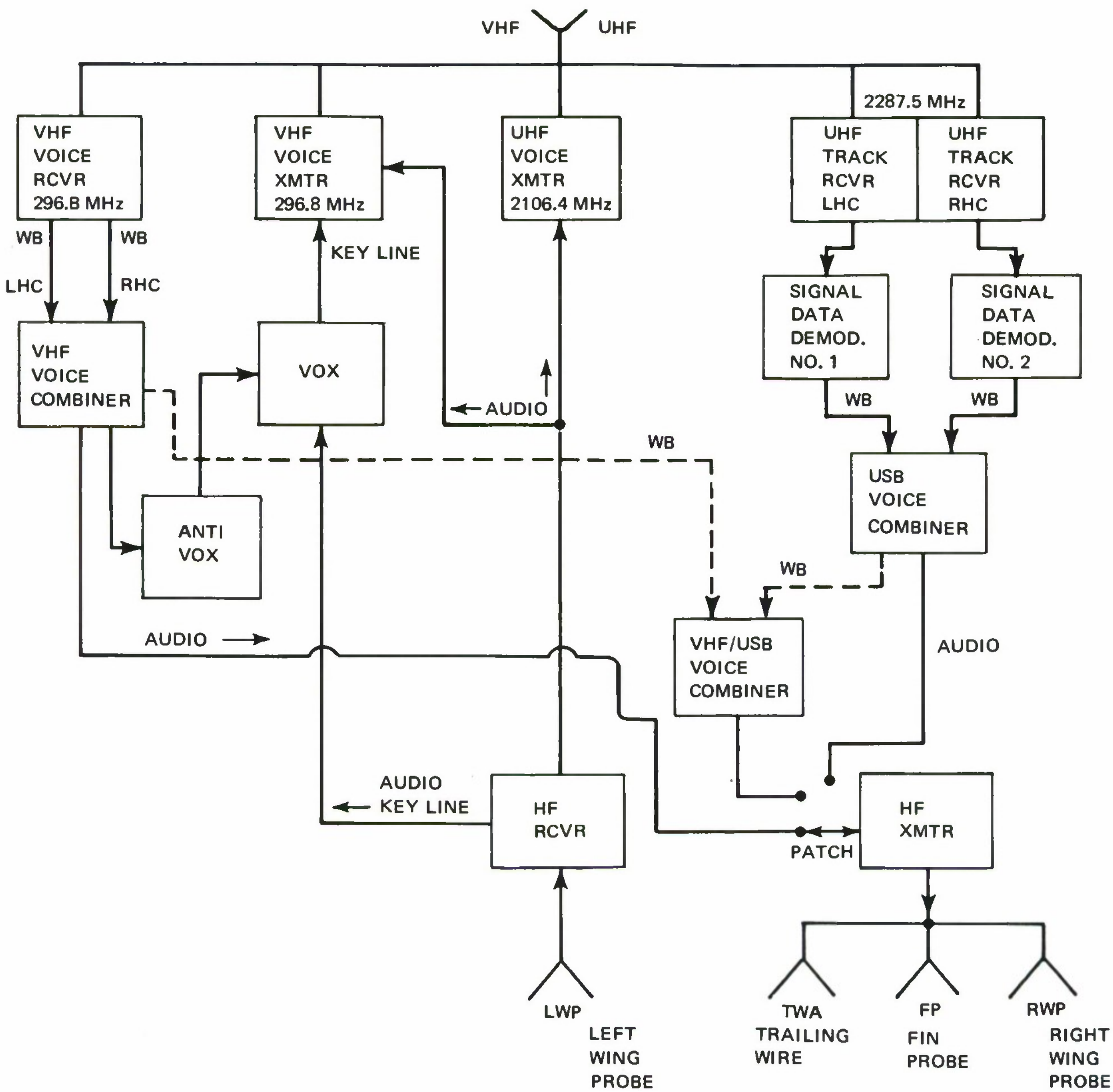


FIGURE 75. A/RIA VOICE RELAY BLOCK DIAGRAM

The audio output of the VHF voice combiner is patched to an HF transmitter. The inhibit signal fed to the anti-Vox disables the Vox so that the VHF received signal will not be interrupted by a received uplink HF signal. The WB output of the combiner is patched to the VHF/USB voice combiner to provide frequency diversity combining.

3.7.4.2 USB Downlink

The voice subcarriers are demodulated from the carriers in the UHF track receivers and fed to the signal data demodulator (SDD). The SDD demodulates the voice subcarriers, providing two USB WB voice outputs at a bandwidth of 11 KHz. These outputs are fed to the USB voice combiner which combines the voice signals and develops two outputs. One output has a 3-KHz bandwidth containing only voice, the other has an 11-KHz bandwidth containing voice and out-of-band noise. The voice output is patched to an HF transmitter, and the WB output is fed to the VHF/USB voice combiner.

3.7.4.3 VHF/USB Downlink

The wideband outputs from the VHF combiner and UHF combiner are combined in the third combiner. Improvement is realized if the two inputs are within approximately 5 dB of one another; if one input is 7 dB higher than the other, the combiner selects the best input and suppresses the other. The output of the third combiner is patched to an HF transmitter.

3.7.4.4 Uplink Voice Relay

The received HF signal is demodulated in the HF receiver and routed to the VHF voice transmitter, AM on the carrier at 85 modulation. The HF receiver keys the VOX, providing a key signal to the VHF transmitter. The duplex UHF link is capable of simultaneous receive and transmit, so the received voice is transmitted UHF with no intervening circuitry. The VHF/USB antenna radiates the two signals to the spacecraft.

3.7.5 System Performance

The A/RIA voice relay system performed as expected once optimum operating techniques were developed. Intelligible voice was relayed in all modes, uplink and downlink.

3.7.5.1 System Performance —— Test 1

Relay combined VHF voice downlink to ground on HF, and HF voice uplink by VHF.

Goal

The goal of this test was to relay intelligible voice through A/RIA.

Conditions

A/RIA VHF voice transmitter output was 100 watts, and HF transmitter output was 1 KW. The HF transmitter operated into either the Right Wing Probe or Fin Probe, while the HF receiver operated from the Left Wing Probe. The VHF transmitter and receiver operated on 296.8 MHz through the VHF/UHF antenna.

TABLE XXXV

VHF Voice Relay Test Results

VHF Terminal	HF Terminal	Flight	Times	Evaluation*
C-121	Douglas Dog	6	1	5/5, no interference
		13	1	Not successful, HF Channel noisy
C-121	Fisher 1	29	1	4/4, broken up by Ft. Sill GCA interfering on VHF.
		30	1	5/5
A/RIA Ground Station	Douglas Dog	7	1	5/5, broken up by Ft. Sill GCA interfering on VHF
A/RIA Ground Station	Fisher 375 (Tulsa)	18	2	4/4, HF Channels noisy, traffic on VHF channel
		19	2	5/5, No interference
		20	4	5/5, No interference

*An explanation of the number code for evaluating voice links is given in Note 1 at the end of this section.

Test Results

The goal of an intelligible VHF-HF two-way voice relay has been met.

3.7.5.2 System Performance —— Test 2

Relay combined USB voice downlink to ground on HF and HF voice uplink by USB with transponder locked up.

Goal

The goal of this test was to relay intelligible voice through A/RIA.

Conditions

A/RIA USB transmitter output was 100 watts and HF transmitter output was 1 KW. The HF transmitter operated into either the Right Wing Probe or Fin Probe, while the HF receiver operated from the Left Wing Probe. The USB transmitter operated on 2106.4 MHz into the VHF/UHF antenna, and the USB receiver operated on 2287.5 MHz from the VHF/UHF antenna.

TABLE XXXVI

USB Voice Relay Test Results

USB Terminal	HF Terminal	Flight	Times	Evaluation
C-121	Douglas Dog	6	1	5/5 No interference on HF
		13	1	Not successful, HF Channel Noisy
C-121	Fisher 1 (Cape)	29	1	5/5, No interference on HF
		30	1	5/5, No interference on HF

Test Results

The goal of an intelligible USB-HF two-way voice relay has been met.

3.7.5.3 System Performance —— Test 3

Relay combined VHF voice downlink by HF, and HF voice uplink by VHF, using pre-recorded tape for voice source, and record received voice.

Goal

The goal of this test was to relay and record intelligible voice.

Conditions

Conditions were the same as Test 1, except that tape recorders were used at the terminals to record the voice transmissions.

Test Results

The goal of intelligible voice recordings at the voice relay terminals was accomplished. The recordings are available.

3.7.5.4 System Performance —— Test 4

Demonstrate that no RFI precludes transmitting and receiving TTY while relaying voice.

Goal

The goal of this test was to relay intelligible voice without interference from TTY.

TABLE XXXVII

VHF Voice Relay Test Results, Pre-Recorded Tape

VHF Terminal	HF Terminal	Flight	Times	Evaluation
A/RIA Ground Station	Fisher 375 (Tulsa)	18	2	Recorded Uplink on one run, downlink could not be recorded because of problems in Fisher 375.
		19	2	Recorded Uplink on one run and Downlink on the other.
		20	2	Recorded Uplink on one run and Downlink on the other.

<u>Conditions</u>

Conditions were the same as Test 1 and 2, except for teletype being sent on an HF channel during the voice relay.

TABLE XXXVIII

Simultaneous Voice Relay, TTY Operations

VHF Terminal	HF Terminal	Flight	Times	Evaluation
C-121	Douglas Dog	6	1	5/5, unaffected by TTY
A/RIA Ground Station	Fisher 375 (Tulsa)	18	2	4/4, unaffected by TTY, interference from noisy HF channel
		19	2	5/5, unaffected by TTY
		20	4	5/5, unaffected by TTY
USB Terminal	**HF Terminal**	**Flight**	**Times**	**Evaluation**
C-121	Douglas Dog	6	1	5/5, unaffected by TTY

<u>Test Results</u>

The test results show that no interference from TTY was present during the several voice relays.

One additional test was considered, namely: Demonstrate that downlink UHF voice will interrupt uplink VHF voice. The test was never performed because of a modification of the VOX system during the early part of Category II testing. This modification gave control of the VOX to whomever talked first. The modification was incorporated because noise on VHF downlink had broken up uplink transmissions, compromising voice relay.

To incorporate this capability into the system, a VHF squelch circuit would have to be added, the VOX modification removed, and an inhibit path added from the third combiner to the VOX. These changes would allow the interruption of uplink VHF voice by downlink USB voice during a USB/VHF combined voice relay, without affecting the USB voice relay.

3.7.6 Functional Reliability/Operability

Establishing a good HF link was the major problem in performing voice relay tests. The HF frequencies assigned for Category II testing were extremely few and often unusable due to high noise levels or traffic. Interference on VHF was due mostly to control towers operating on or near the assigned VHF frequency, causing the anti-VOX to inhibit the VOX and make transmission by A/RIA impossible.

Some USB voice relays with the C-121 aircraft were compromised by operator error. These included improper antenna choice by the C-121 operator, causing weak and unusable signals. Also, slight detuning of the transponder by the A/RIA operator caused an over-stress in the loop when voice transmission occurred, resulting in transponder unlock. For operations with Apollo, it is planned to set and monitor the UHF frequency with a frequency counter, and adjust for known doppler using a prepared chart. (See A/RIA Tech Note A0136.)

Less than optimum VOX adjustment resulted in a loss of some voice relay, but usually did not adversely affect the test because adjustments were made as soon as a misalignment was observed. Once a workable technique of VOX adjustment was developed, few problems were experienced.

On Flight 20, the first scheduled voice relay could not be performed due to the operator tuning the VHF receiver to the wrong frequency.

3.7.7 Design/Operational Problems

Problem

The VHF receiver contains normal in-band noise when no carrier is being received, making the downlink voice relay noisy.

Recommendation

It is recommended that ECP 57 (squelch modification) be approved.

NOTE 1

An abbreviated form of the SINPO code used to evaluate voice communication links follows:

Scale Rating	Signal Strength	Overall Readability
5	Excellent	Excellent
4	Good	Good
3	Fair	Fair
2	Poor	Poor
1	Barely Audible	Unusable

3.8 HF COMMUNICATIONS

Summary of Test Results

The HF communications subsystem was tested on all Category II flights. HF voice and TTY links were successfully established using simplex, duplex, single sideband, independent sideband, frequency diversity, and sideband diversity. Teletype was operated using single, twin, and quad diversity. All HF equipment was used during the Category II flights. HF links were established and maintained using the left wing probe, right wing probe, fin probe, and trailing wire antennas. Five-by-five contacts were made at ranges from 90-nm to 5500-nm. System operability/reliability was satisfactory. The HF voice combiner was the only design problem experienced during Category II. The trailing wire antenna mechanical problem is discussed in Section 3.13.

3.8.1 Tests Performed

Test 1 Establish HF communications on all Category II flights.

Test 2 Establish voice communications using non-diversity and sideband diversity reception; demonstrate HF combiner operation under diversity reception; demonstrate non-diversity and sideband diversity transmit.

Test 3 Establish voice communications using frequency diversity, transmit, and receive. Demonstrate HF combiner operation under frequency diversity.

Test 4 Demonstrate operation of independent sideband voice on upper SB, and TTY on lower SB.

Test 5 Demonstrate 2000-nm HF range.

Test 6 Demonstrate and evaluate the A/RIA HF antennas, including the right wing probe, left wing probe, fin probe, and trailing wire during transmit and receive.

Test 7 Establish teletype communications using a pre-programmed tape from the typing reperforator, the keyboard send/receive unit, or both.

Test 8 Demonstrate single, dual, and quad tone diversity teletype operation.

Test 9 Evaluate teletype doppler correction.

Test 10 Use and evaluate as many receive/transmit modes and equipment combinations as possible.

3.8.2 Test Environment

The HF voice and teletype subsystem in the test aircraft used four different terminals during most of the Category II flight tests.

a. Douglas Dog HF station at Tulsa airport

b. A ground-based A/RIA on the ramp at Tulsa airport

c. Cape Kennedy (several different stations)

d. A/RIA mock-up at Bendix Radio in Baltimore

Sites farther from the aircraft were used from time to time in establishing a long range capability.

Most of the aircraft flight time was logged flying a racetrack pattern within 150-nm of the Tulsa airport. Deviations from this occurred during the following periods:

a. Flights 8 and 9 were flown off Corpus Christi, Texas, in support of Gemini 12.

b. Flight 26 was enroute to ETR for support of the ballistic missile.

c. Flight 27 was a flight from Cape Kennedy to the Antigua area and return.

d. Flight 28 was off Cape Kennedy and enroute to Tulsa.

e. Flight 30 was from Tulsa to the Gulf of Mexico and back for tests with the C-121 over water.

While flying a racetrack near Tulsa, HF voice communications were normally maintained between the aircraft and A/RIA 374 or A/RIA 330 on the ground, and between the aircraft and the Douglas Dog HF station.

A description of the primary HF terminals follows:

a. Douglas Dog at Tulsa Airport. This terminal consisted of an AN/ARC-65 SSB transceiver capable of voice on the upper sideband or Amplitude Modulated Equivalent (AME), and a Collins, type 30K, Model 5, transmitter. The AN/ARC-65 was used simplex, with a power output of 300 watts, and a receiver sensitivity of 10 microvolts at the receiver input. No teletype capability was available.

b. A/RIA 375 or A/RIA 330 at Tulsa. These aircraft permitted a total checkout of the airborne test aircraft, since they had identical equipment and capabilities.

c. Cape Kennedy HF Terminal. A breakdown of Cape Kennedy equipment is not available. The several HF stations were capable of testing virtually all combinations of A/RIA modes and configurations. Also, Cape Kennedy permitted the use of facilities actually to be used for Apollo.

d. A/RIA Mock-Up at Bendix Radio (Baltimore). The A/RIA mock-up has equipment identical to an A/RIA. The mock-up was used primarily for teletype and doppler correction tests, providing longer range communications than the Tulsa-based A/RIA's could provide.

Other terminals contacted included Hawaii, Pretoria, Ascension, Antigua, Maine, Illinois, Vandenburg, and a ship at sea.

3.8.3 Data Collection Techniques

In evaluating HF performance, data was gathered from completed flight cards, A/RIA HF station logs, flight reports, interviews with the test aircraft operator, reports from terminals contacted, CEC oscillograph recorders, event recorders, and TTY messages.

The method of reducing data is different for each test; a clearer presentation has been achieved by including data reduction details under the individual tests performed.

3.8.4 System Configuration

The HF system configuration for voice and teletype tests is shown in Figures 76 through 79. These figures show general configurations for transmitting and receiving HF voice and teletype; the changes in configuration for specific operating modes are covered under the individual tests.

3.8.4.1 HF Transmit Configuration (See Figure 76)

The voice input for downlink transmission was the HF Operator's voice, the Mission Coordinator's voice, or spacecraft downlink voice from the voice and telemetry

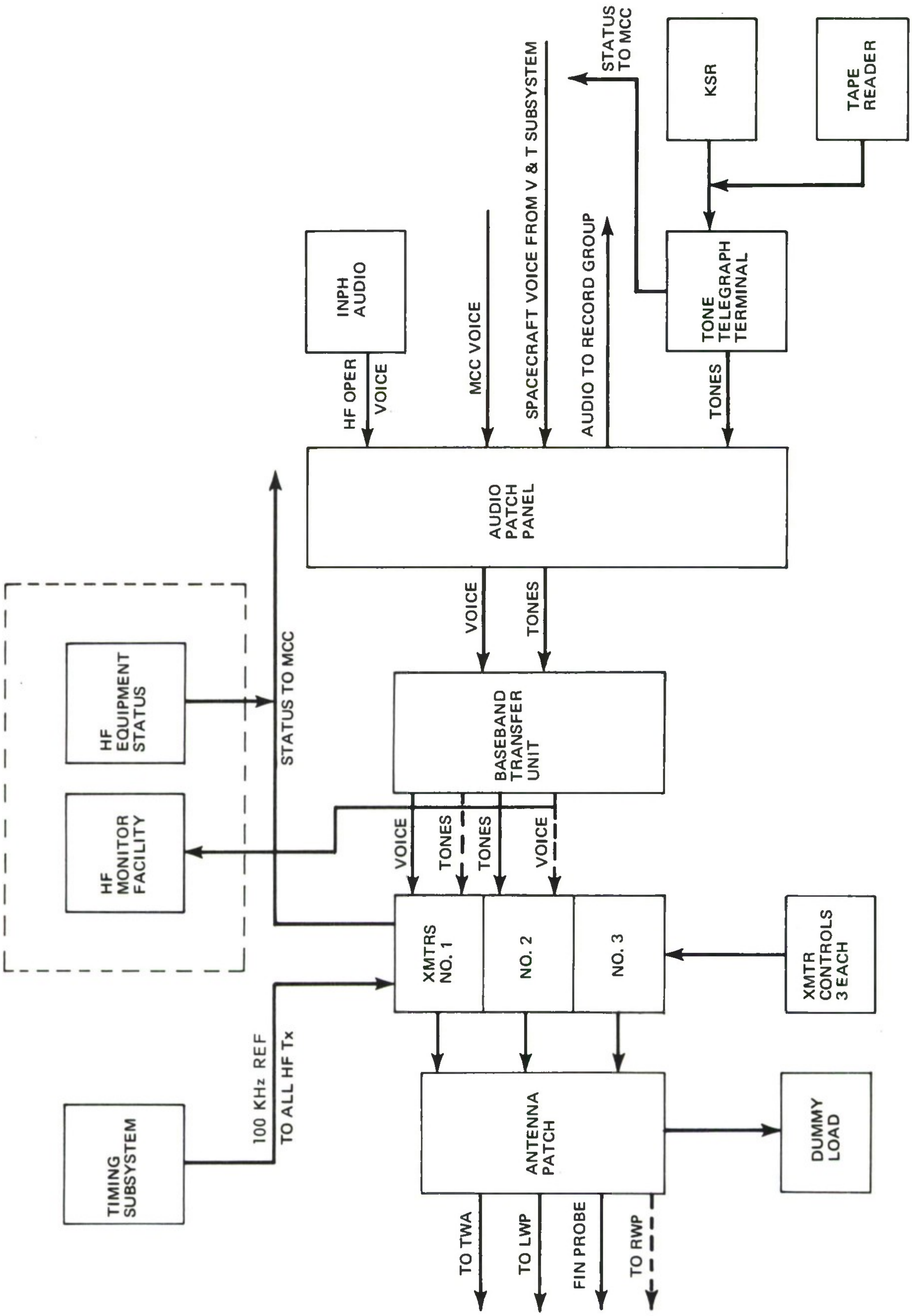


FIGURE 76. HF TRANSMIT CONFIGURATION

subsystem. Voice was normally transmitted on one sideband of a transmitter and teletype on a second sideband of the same transmitter. Each transmitter has four sidebands available. When voice and TTY were transmitted on the same transmitter, either the left wing probe, the fin probe, or the trailing wire was used. Whenever separate voice and TTY transmitters were used, two of the three available transmit antennas were employed.

The HF operator has GO/NO-GO selectors on the HF Equipment Monitor to allow him to notify the Mission Coordinator of equipment status. There is a pre-set power level indicator in the MCC for each HF transmitter which indicates when each transmitter is transmitting. The audio input level to each transmitter was adjusted by the HF Operator at the Equipment Monitor and Audio Center.

3.8.4.2 HF Receive Configuration (See Figure 77)

The HF signal was normally received by the right wing probe and patched through an untuned antenna coupler and the patch panels to the HF receivers. Each receiver line had a tunable bandpass filter, requiring a 10 percent frequency separation between transmit and receive. Two receivers were normally used on the same frequency, the third receiver acted as standby. Receiver outputs were monitored by the operator at the HF monitor.

The voice received at the audio patch panel was sent to the audio recorder, the PMEE interphones, and the uplink voice transmitters. The VHF and UHF voice transmitters were patched to the HF receive system for voice relay. The three audio combiners were used during diversity combining tests.

3.8.4.3 Simplex Configuration (See Figure 78)

Owing to limitations in HF terminals utilized during the Category II Flight Test Program, it was necessary to configure the A/RIA for simplex operation. Although the A/RIA HF system is not designed to operate simplex non-standard connections made it possible. This unique configuration is shown in Figure 78.

The linear power amplifier includes a transmit/receiver (Tx/Rx) relay that is normally not used. A long test cable was used to patch the receive terminal of the Tx/Rx relay to the HF receiver.

3.8.4.4 Teletype Group Interconnections (See Figure 79)

One of the two keyboards or the tape reader was used to originate outgoing messages. A sequential combination of current pulses were fed through the loop current control and patch panel to the keyers, where the current pulses were converted to tones. One, two, or four of the 15 available keyers were keyed simultaneously for single, dual, or quad tone diversity. A sixteenth channel, a fixed tone at 425 Hz, is used for doppler correction. The 15 keyer channel capability (595 Hz to 2975 Hz) is provided to compensate for frequency selective fading. The current pulses change the keyer output

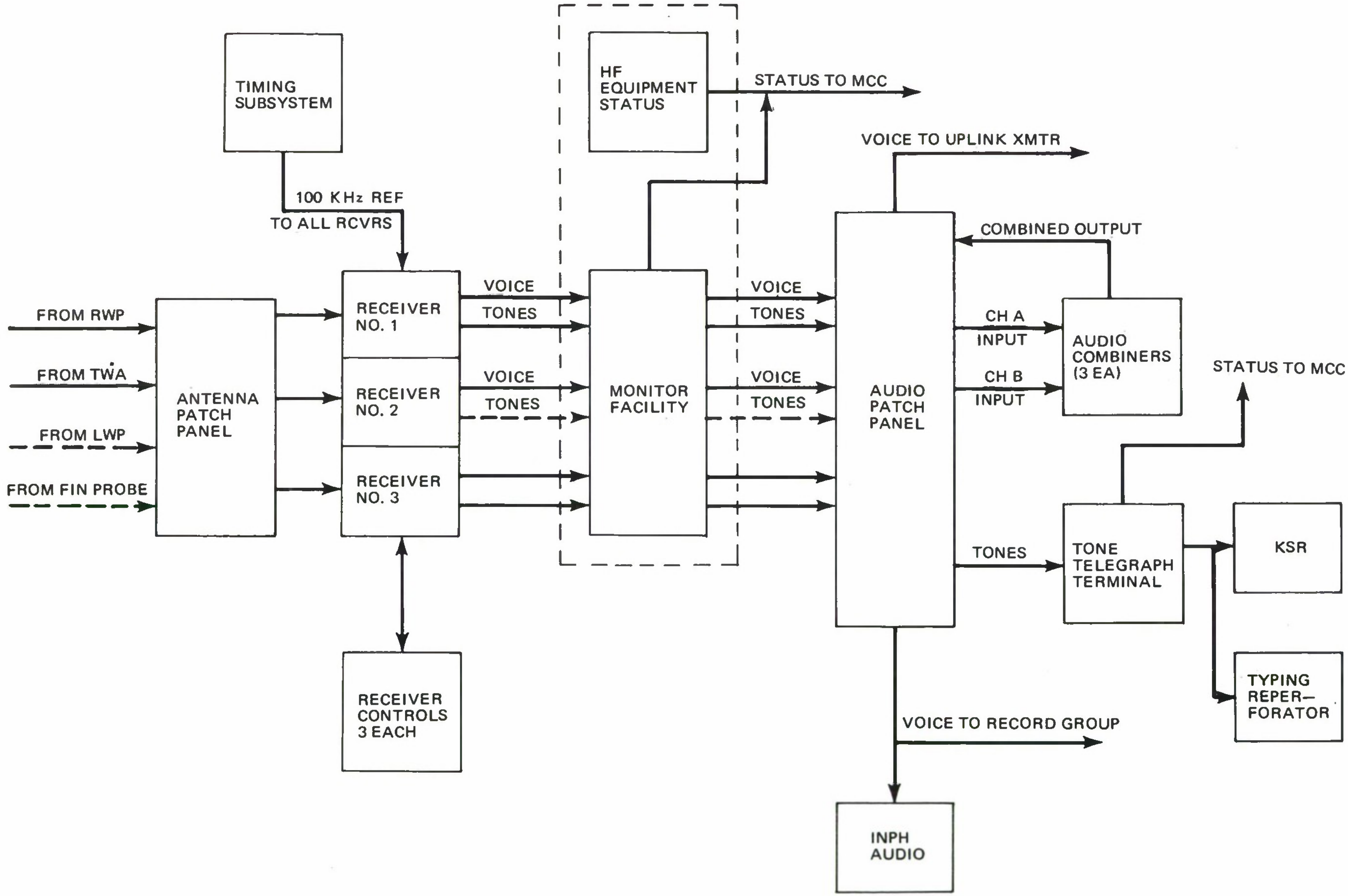


FIGURE 77. HF RECEIVE CONFIGURATION

frequency by ± 42.5 Hz. The FSK tones from the keyers are combined with the 425 Hz doppler correction tone and modulate the SSB transmitter.

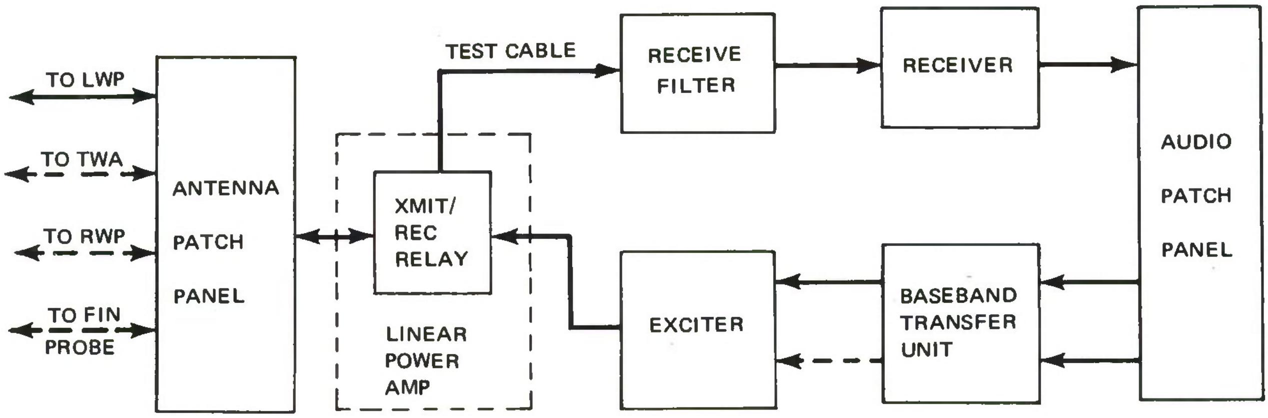


FIGURE 78. SIMPLEX CONFIGURATION

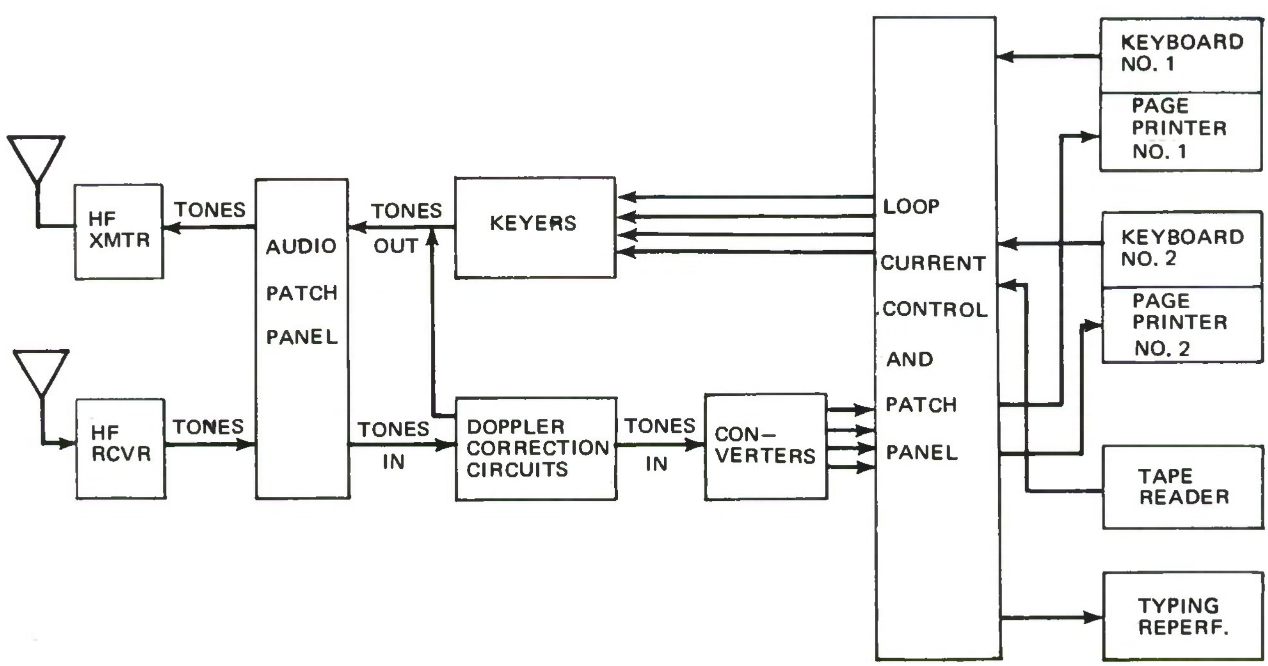


FIGURE 79. TELETYPE GROUP CONFIGURATION

3.8.4.5 TTY Receive

Teletype messages are received as FSK tone-modulated sidebands by the HF receiver. The receiver demodulates the sideband and sends the FSK tones and the doppler correction tone to the doppler corrector. The doppler corrector removes frequency shift by comparing the received doppler tone with a reference tone. The corrected tones are sent to the converter which converts the tones back to current pulses. The pulses are routed through the loop current control to the typing reperforator and/or the page printer(s). The reperforator cuts a tape of the message for later playback, while the printer prints out the message in real time.

3.8.5 System Performance

The HF communications subsystem was used continuously throughout the Category II Test Program, with voice communications established with the Tulsa HF station, Cape Kennedy, Bendix, Baltimore, and several other stations of opportunity, at ranges of up to 5500-nm. All antenna systems were operated, but with some restrictions on usage of the trailing wire antenna due to mechanical problems. Communications were conducted via duplex and simplex (with special cabling) modes of operation. Simultaneous teletype operation was demonstrated with various types of diversity, and concurrently with voice relay operations. The results of the tests conducted are detailed in the following paragraphs.

3.8.5.1 System Performance —— Test 1

Establish HF voice communications on all Category II test flights.

Goal

Establish intelligible two-way voice link with several different ground terminals to demonstrate system reliability and operability.

Conditions

The system was operated on a day-to-day basis in a manner similar to that expected under operational usage by the customer. The various modes and configurations were utilized under different environments.

Test Results

HF voice links were successfully established on 25 of the 26 test flights. All possible equipment modes and configurations were successfully tested. Voice links were established at ranges from 90-nm to 7800-nm. The HF system was operated in the actual design environment during flights against Gemini XII (Flights 8 and 9) and the ballistic missile (Flight 27). Link reliability was from excellent to poor, the variable being atmospherics and the number of alternate receive-transmit frequencies available. Equipment reliability was satisfactory; intelligible HF voice links were established on

all flights except Flight 13, where communications were not possible owing to inadequate frequency assignments. Early in the flight test program the frequencies assigned were not optimum for daytime operation.

Data supporting these test results consist of an A/RIA HF station log for each flight. (See Appendix II.) Also, the various modes used during the program are tabulated in Table XLIV following Test 7.

3.8.5.2 System Performance —— Test 2

Establish voice communications using non-diversity and sideband diversity reception; demonstrate HF combiner under diversity reception. Demonstrate non-diversity and sideband diversity during transmit.

Goal

Demonstrate sideband diversity during receive/transmit modes.

Conditions

These tests were conducted while the test aircraft was flying a standard racetrack pattern against the A/RIA ground station. The HF terminal was A/RIA 375 parked on the ramp at the Tulsa airport. The specific test configuration is shown in Figures 80 and 81.

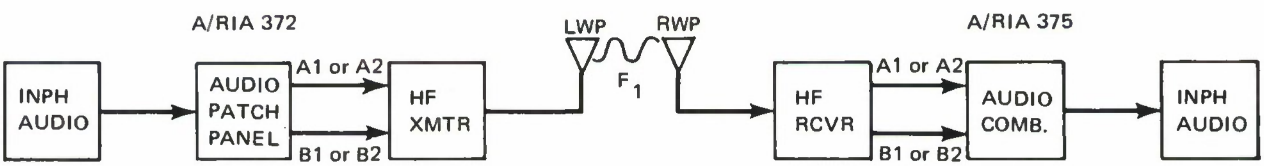


FIGURE 80. AIR-TO-GROUND SIDEBAND DIVERSITY CONFIGURATION

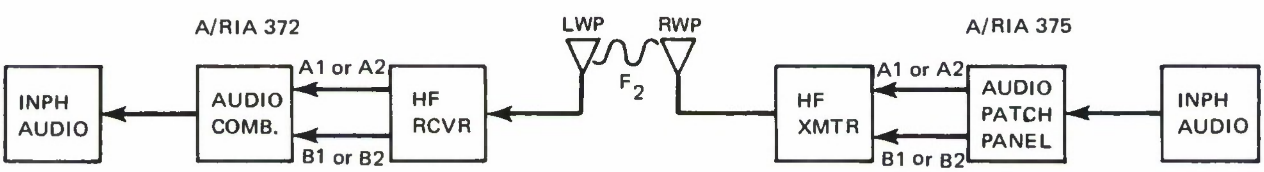


FIGURE 81. GROUND-TO-AIR SIDEBAND DIVERSITY CONFIGURATION

The HF operator in the test aircraft established the air-to-ground link as shown in Figure 80, using either sidebands A1 and B1 or A2 and B2. The received signals were demodulated in the receiver and combined by the HF audio combiner. (See Table XXXIX.)

Test Results

As shown in Table XXXIX, the sideband diversity tests were performed on Flights 11, 12, and 16. The HF voice link was operated simplex on Flights 11 and 12, where sidebands A1 and B1 were transmitted and received. The system was operated duplex on Flight 16 using sidebands A2 and B2. The link intelligibility evaluations were made by operator observations and HF station logs. It is difficult to accurately assess the improvement, if any, realized by audio combining of normal voice communications. The intelligibility of the combined voice was evaluated as equal to the uncombined.

3.8.5.3 System Performance —— Test 3

Establish voice communications using frequency diversity transmission and reception. Demonstrate HF combiner using frequency diversity.

Goal

Show advantage of using frequency diversity transmission or reception over non-diversity transmission or reception. Demonstrate the improvement, if any, resulting from combining frequency diversity receptions.

Conditions

These tests were conducted on Flights 19 and 20 while the test aircraft was flying a standard racetrack pattern against the ground station. The HF terminal was A/RIA 375 parked on the ramp at the Tulsa airport. Further tests were performed on Flight 27 with Cape Kennedy, while the test aircraft was down-range approximately 1400-nm. The test configuration used for these tests is as shown in Figure 82.

For downlink communications interphone audio modulated the upper sideband (A1) of two transmitters on different frequencies. One transmitter was patched to the left wing probe, the other to the fin probe. The signal was received on the right wing probe at A/RIA 375 and patched to two receivers tuned to the different frequencies. The demodulated outputs of the receivers were fed to the audio combiner. Uplink communications were the same as shown in Figure 82, except the A/RIA 375 transmitted and A/RIA 372 received the voice.

Test Results

The results of the frequency diversity tests are shown in Table XL.

TABLE XXXIX

Sideband Diversity Test Results

Flight No.	Transmit Frequency	Receive Frequency	Mode	Sideband	Results
11	6.685	6.685	Simplex Sideband Diversity	A1, B1	Combined intelligibility equal to uncombined.
12	6.685	6.685	Simplex Sideband Diversity	A1, B1	5/5, combined intelligibility equal to uncombined.
16	14.553	6.685	Duplex Sideband Diversity	A2, B2	5/5, combined intelligibility equal to uncombined.

TABLE XL

Frequency Diversity Test Results

Side Band	Intelligence	Transmit Frequency	Receive Frequency	Mode	Flt	No. Times	Results
A1 B1 A1 A1	Voice Voice Voice	20.475 14.553	 6.685 17.553	Frequency Diversity Combining	19	3	Echo Effect, Output Fluctuations
A1 A1 A1 A1	Voice Voice Voice Voice	5.810 6.7135	 13.635 10.740	Frequency Diversity Combining	22	1	Echo Effect, Output Fluctuations
A1 B1 A1 B1 A1	Voice TTY TTY Voice Voice	7355 7355 10.780	 9.043 9.043 10.780	ISB Down-link Duplex Frequency Diversity	27	1	Excellent voice and TTY. 10.780 MHz used as simplex backup. No diversity combining was attempted. Uplink reception was by operator manual selection of best uplink voice channel.

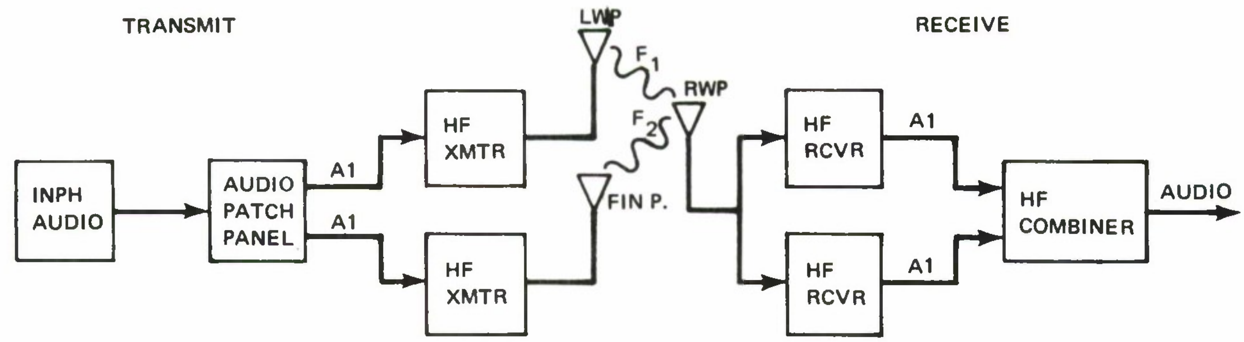


FIGURE 82. FREQUENCY DIVERSITY CONFIGURATION FOR DOWNLINK COMMUNICATIONS

Frequency diversity combining was performed on Flights 19 and 22. The combined voice output varied in intelligibility and had a pronounced echo effect. These characteristics have been attributed to a lack of frequency coherence between the two audio signals prior to combining. It has been determined that the combiner will not satisfactorily combine audio under conditions of equal signal inputs.

For Flight 27, the system was configured so that the operator manually selected the best of the two uplink frequencies from the combiner. A simplex link was used for standby while voice and teletype tests were being conducted on a duplex pair. Both receiver inputs were patched to the combiner, and the combiner switch placed in either the CHANNEL A or CHANNEL B position (rather than DIVERSITY). Test results were excellent and very good voice and teletype links were maintained.

3.8.5.4 System Performance —— Test 4

Demonstrate Independent Sideband operation (ISB), with voice on one sideband and teletype on the other.

Goal

Show advantages of ISB mode of operation.

Conditions

Tests were conducted using two primary HF terminals; one terminal was an A/RIA parked on the ramp at Tulsa and the other terminal was the Cape Kennedy HF station. The ground-based A/RIA was used when the test aircraft was flying racetrack patterns against the A/RIA ground station. The Cape Kennedy facility was used under the following conditions:

a. A/RIA flying race tracks near Tulsa.

b. A/RIA located down-range at ETR while tracking a ballistic missile.

c. While enroute from Patrick AFB to Tulsa.

The Douglas Dog HF station at Tulsa and the A/RIA mock-up at Bendix Radio were also used as terminals during the program. The system configuration utilized for these tests is shown in the simplified block diagram below (Figure 83):

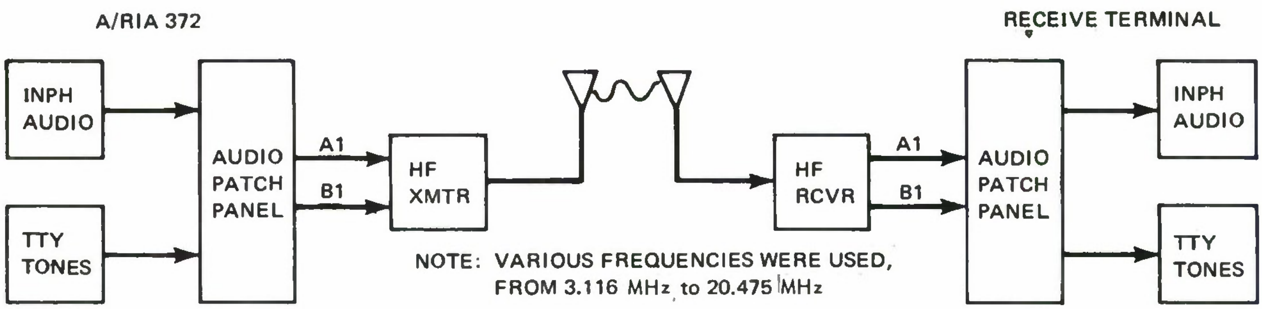


FIGURE 83. INDEPENDENT SIDEBAND CONFIGURATION

Test Results

The results of Independent Sideband tests are shown in Table XLI.

Voice and Teletype ISB tests were conducted on thirteen flights. There was no noticeable crosstalk between sidebands, and voice and teletype were both generally good. Whenever the voice link was noisy, teletype messages were also less than 100 percent copies; the quality of the HF link is determined by propagational reliability.

The ISB mode of operation is preferred to sideband diversity because only one transmitter and receiver are required to establish and maintain both a voice and TTY link. Furthermore, it is easily possible to switch to frequency diversity ISB with a simplex backup link. Once authorization is obtained for utilizing four-channel multiplex, teletype and voice sideband diversity are possible on the same link. The goal was met. The advantages are as described above. Table XLI shows that ISB operation has been thoroughly tested and that test results were more than satisfactory.

3.8.5.5 System Performance —— Test 5

Demonstrate HF communications at 2000-nm range.

Goal

Demonstrate long range communications capability.

Conditions

Most HF terminals monitor specific frequencies using a simplex configuration. All A/RIA long range voice links used the simplex configuration as defined in Section 3.8.4 (System Configuration).

TABLE XLI

Independent Sideband Test Results

Side Band	Intelli-gence	Tx Freq MHz	Rx Freq MHz	Mode	Flt	No. Times	Terminal	Results
A1 B1	Voice/ TTY	6.615	3.116	ISB	6	1	Douglas Dog	Preliminary test for interference Douglas Dog terminal has no TTY-Voice 5/5
A1	Voice/ TTY	6.685	3.116	ISB	10	2	A/RIA 330	HF voice very noisy. TTY - 5 errors/ 68 lines.
B1 & A1 A2 B2	Voice/ TTY/ IPPS Timing Sync	6.685	6.685	Simplex	11	2	A/RIA 330	Successful test. TTY - Tx 17 lines/ no errors; TTY - Rx 7 lines/3 errors. Sync to within .5 M/Sec
A1 A2	Voice/ TTY	20.475	20.475	Simplex ISB	14	2	BXR	Voice - 5/5 TTY Tx - 185 lines/130 errors TTY Rx - 64 lines/21 errors
A1 A2	Voice/ TTY	14.553	20.475	ISB	14	2	BXR	Voice - 5/5 TTY Tx - 185 lines/ 17 errors TTY Rx - 46 lines/6 errors
A2 & B2 B1	Sideband Diversity Voice/ TTY	14.553	6.685	ISB	16	1	A/RIA 375	5/5 Uplink Voice Noisy downlink Doppler correction - Good TTY - 49 lines/2 errors
A1	Voice Relay/	20.475	6.685	ISB	18	1	A/RIA 375	Voice Relay - 4/4
B1	HF Op Comm/	11.993	6.685		18	1		HF Comm - 4/4
A2	TTY							TTY - Not evaluated

TABLE XLI (Continued)

Side Band	Intelli- gence	Tx Freq MHz	Rx Freq MHz	Mode	Flt	No. Times	Terminal	Results
A1 B1	Voice/ TTY	10. 74 & 13. 635 to 20. 390 5. 810	6. 685	ISB	20	3	A/RIA 375	Voice - Noisy but readable TTY - 420 lines 1. 1 error/line
A1 B1	Voice/ TTY	20. 390	7. 355	ISB	21	2	A/RIA 330	Voice - 5/5. TTY Tx - 30 lines/0 errors; TTY Rx - 18 lines/5 errors
A1 A2	Voice/ TTY	5. 810	7. 355	ISB	22	1	BXR	Voice - 5/5; TTY - 160 lines received, 70 readable.
A1 A2	Voice/ TTY	5. 810	10. 740	ISB	22	1	A/RIA 375	16 lines/5 errors
A1 A2 A1 B2	Voice/ TTY Voice/ TTY	5. 810 6. 7135	13. 635 10. 740	Freq. Diver. ISB	22	1	A/RIA 375	Voice - 5/5 uncombined TTY - 52 lines/48 errors TTY - No combining done on TTY Using Quad Diver. 32 lines/7 errors.
B1 A1	Voice/ TTY	10. 370	7. 355	ISB	23	5	Cape Kennedy	Voice - 5/5 TTY - 112 lines/132 errors
A1 B1 A1 B1	Voice/ TTY TTY/ Voice	7. 355 change 11. 407 change 13. 878	9. 043 change 12. 140	ISB	27	7	Cape Kennedy	Voice - 5/5 TTY - good link, 90 to 100% copy Teletype data not provided by AFETR.
A1 B1	TTY/ Voice	4. 900	9. 043	ISB	28	6	Cape Kennedy	Voice - 5/5 TTY - 458 lines/165 errors

Test Results

All long range links (over 2000-nm) established during Category II test flights are tabulated in Table XLII.

Long-range contacts were made on several flights during the test program. Ascension picked up an attempted call to Cape Kennedy on Flight 5 and notified the Cape. The A/RIA was configured for duplex so a direct reply from Ascension was impossible. Ascension and Antigua were contacted and a 5/5 link established during ground operations prior to Gemini coverage. A very weak contact was made with Antigua and Loring AFB, Maine, during Flight 24. On Flight 28, four long-range contacts were made while flying in the area of Cape Kennedy and enroute from the Cape to Tulsa. Although other contacts were made, only those over 2000-nm are shown in Table XLII. Additional long-range contacts were made on Flight 30.

The tabular listing presents data satisfying the HF requirement for establishing HF links beyond 2000-nm.

3.8.5.6 System Performance —— Test 6

Demonstrate and evaluate the A/RIA HF antennas, including the right wing probe, left wing probe, fin probe, and trailing wire antenna during transmit and receive.

Goal

Demonstrate that all HF antennas operate satisfactorily, and ascertain the advantage of using the trailing wire antenna (TWA).

Conditions

During Category II testing, the left wing probe (LWP) was normally used for transmitting and the right wing probe (RWP) for receiving. The fin probe (FP) and trailing wire antenna (TWA) were utilized often enough to evaluate their operation. Transmitter power output for all tests was 1,000 watts PEP. Receive system sensitivity was to specifications, i.e., one microvolt input at the receiver yielded a 10 dB SNR.

Test Results

Table XLIII lists all HF links established during the Category II Test Program and the antenna used for transmit and receive.

Long- and short-range communications were established at various frequencies using the left wing probe for transmitting and the right wing probe for receiving. Communications were loud and clear at ranges from 120-nm to 1100-nm. Communications were established at much greater ranges using the left wing probe for simplex operation. Greater range is possible with simplex because the stations contacted normally

TABLE XLII

Long Range Voice Contacts

Side Band	Tx Freq. (MHz)	Rx Freq. (MHz)	Mode	Flight	Times	Terminal	Range N. M.	Results
A1	10.780		Duplex	5	1	Ascension	5500	Picked up by Ascension 3/3
A1	10.780	10.780	Simplex	Ground Oper.	1	Ascension	5500	5/5
A1	10.780	10.780	Simplex	Ground Oper.	1	Antigua	2200	5/5
A1	10.780	10.780	Simplex	24	1	Antigua	2200	1/1
A1	11.176	11.176	Simplex	24	1	Loring AFB Maine	2500	1/1
A1	10.780	10.780	Simplex	25	1	Antigua	2200	4/4
A1	6.738	6.738	Simplex	28	1	Ship Victor 15-40N 27-20W	3100	5/5
A1	13.218	13.218	Simplex	28	1	Vandenberg	2100	5/5
A1	10.780	10.780	Simplex	28	1	Ascension	5400	4/4
A1	13.218	13.218	Simplex	28	1	Hawaii	3100	1/1
A1	10.780	10.780	Simplex	30	1	Antigua	2000	3/3
A1	20.390	20.390	Simplex	30	1	Ascension	5000	2/2
A1	13.218	13.218	Simplex	30	1	Vandenberg	2100	3/3
A1	20.390	20.390	Simplex	30	1	Ascension	5000	3 to 4/4
A1	20.390	20.390	Simplex	30	1	Pretoria	300	1/1

TABLE XLIII

HF Antenna Test Results

Tx Freq	Tx Ant	Rx Freq	Rx Ant	Mode	Mode Type	Flt	No. Times	Terminal	Range	Results
6.685	LWP	3.116	RWP	Duplex	Voice	3	1	Douglas Dog	90	Downlink 4/4 Uplink 5/5 broken
6.685	LWP	3.116	RWP	Duplex	Voice	5	1	Douglas Dog	120	4/4
10.780	LWP	9.043	RWP	Duplex	Voice	5	1	Cape Kennedy	1000	4/4
10.780	LWP	9.043	RWP	Duplex	Voice	5	1	Ascension	5500	3/3 Ascension monitored call to Cape Kennedy
10.780	LWP	9.043	RWP	Duplex	ISB	6	1	Cape Kennedy	1000	4/4
6.685	LWP	3.116	RWP	Duplex	Voice	6	1	Douglas Dog	120	5/5
6.685	LWP	3.116	RWP	Duplex	Voice	7	1	Douglas Dog	120	5/5
10.780	LWP	10.780	LWP	Simplex	Voice	7	1	Cape Kennedy	1000	5/5
10.780	FP	10.780	FP	Simplex	Voice	Grd Oper.	1 1	Cape Kennedy Ascension	1000 5500	5/5 5/5
							1	Antigua	2200	5/5
10.780	LWP	10.780	LWP	Simplex	Voice	8	1	Cape Kennedy	800	5/5
14.585	LWP	17.552	RWP	Duplex	Voice	8	1	Cape Kennedy	800	5/5
20.390	LWP	17.552	RWP	Duplex	Voice	8	1	Cape Kennedy	800	5/5
10.780	LWP	17.552	RWP	Duplex	Voice	8	1	Cape Kennedy	800	5/5
11.988	LWP	17.552	RWP	Duplex	Voice	8	1	Cape Kennedy	800	5/5
10.780	FP	10.780	FP	Simplex	Voice	9	2	Cape Kennedy	800	5/5
20.475	TWA	17.552	RWP	Duplex	Voice	9	1	Cape Kennedy	800	5/5
13.878							1			
14.585							1			
6.685	TWA	3.116	RWP	Duplex	Tx-Voice Rx-ISB	9	1	A/RIA 330	600	5/5
6.685	LWP	3.116	RWP	Duplex	ISB	10	3	A/RIA 330 Douglas Dog	120	HF Voice very noisy TTY 5 errors/68 lines
6.685	TWA	6.685	TWA	Simplex	ISB	11	1	A/RIA 330 Douglas Dog	120	Weak-with fading TTY-Tx 17 lines/1 error; Rx 7 lines/ 3 errors
6.6850	LWP	6.6850	LWP	Simplex	Sideband Diversity	12	1	Douglas Dog	120	5/5
		6.6848			SSB		1			5/5
		6.6849			SSB		1			5/5
6.685	LWP	6.685	LWP	Simplex	Voice	14	2	Douglas Dog A/RIA 375	120	5/5
6.685	LWP	6.685 3.116	LWP RWP	Simplex Duplex	Voice Voice	14	1 1	A/RIA 375 Douglas Dog	120	5/5
14.250 20.475	LWP	14.250 20.475	LWP	Simplex	ISB	14	1	BXR Baltimore	1300	5/5
14.553	LWP	20.475	RWP	Duplex	ISB	14	1	BXR	1300	5/5
6.685	LWP	6.685	LWP	Simplex	Voice	15	1	Douglas Dog A/RIA 375	120	No contact during early part of flt. Established 5/5 contact during Run No. 4.
6.685	LWP	3.116	RWP	Duplex	Voice	15	1	A/RIA 375	120	5/5

TABLE XLIII (Continued)

Tx Freq	Tx Ant	Rx Freq	Rx Ant	Mode	Mode Type	Flt	No. Times	Terminal	Range	Results
6.685	LWP	6.685	LWP	Simplex	Voice	16	2	A/RIA 375 Douglas Dog	120	5/5
14.553	LWP	6.685	RWP	Duplex	Voice	16	1	A/RIA 375	120	Uplink 5/5 Downlink Noisy
3.116	LWP	6.685	RWP	Duplex	Voice	18	1	A/RIA 375	120	Noisy 4/4
14.553	LWP & FP	6.685	RWP	Duplex	ISB	18	2	A/RIA 375	120	Noisy 4/4
20.475	LWP & FP	6.685	RWP	Duplex	ISB	18	1	A/RIA 375	120	Noisy 4/4
11.993	LWP & FP	6.685	RWP	Duplex	ISB	18	1	A/RIA 375	120	Noisy 4/4
6.685	LWP	6.685	LWP	Simplex	Voice	19	1	A/RIA 375 Douglas Dog	120	5/5
20.475 14.553	LWP FP	6.685	RWP	Duplex Freq Diver.	Voice	19	1	A/RIA 375	120	Uncombined 5/5 Combined has echo effect.
20.475 14.553	LWP FP	6.685 12.553	RWP RWP	Duplex Freq Diver.	Voice	19	1	A/RIA	120	Uncombined 5/5 Combined has echo effect.
20.475 14.553	LWP FP	6.685 17.553	RWP RWP	Duplex Freq Diver.	Voice	19	1	A/RIA	120	Uncombined 5/5 Combined has echo effect.
6.685	LWP	6.685	LWP	Simplex	Voice	20	1	A/RIA 375	120	Noisy but readable
10.740 13.635	LWP RWP	6.685 6.685	FP FP	Duplex Freq Diver.	ISB	20	1	A/RIA 375	120	Interference from Tx on Wing Probes
10.740 13.635	LWP FP	6.685 6.685	RWP	Duplex Freq Diver.	ISB	20	1	A/RIA 375	120	Noisy but readable Interference disappeared
10.740 20.390	LWP FP	6.685 6.685	RWP	Duplex Freq Diver.	ISB	20	1	A/RIA 375	120	Noisy but readable
10.740 5.810	LWP FP	6.685 6.685	RWP	Duplex Freq Diver.	ISB	20	1	A/RIA 375	120	Noisy but readable
13.635	FP	13.635	FP	Simplex	Voice	21	1	A/RIA 330 BXR	120 1300	Intelligible link No contact
10.740	LWP	10.740	LWP	Simplex	Voice	21	1	A/RIA 330 BXR	120 1300	Intelligible link No contact
13.635	FP	13.635	FP	Simplex	Voice	21	1	A/RIA 330 BXR	120 1300	Intelligible link Poor contact
10.740	FP	10.740	FP	Simplex	Voice	21	1	A/RIA 330 BXR	120 1300	Intelligible link Poor contact
6.685	FP	10.740	FP	Simplex	Voice	21	1	A/RIA 330 BXR	120 1300	Intelligible link Poor comm.
10.780	FP	10.780	FP	Simplex	Voice	21	1	Cape	1000	5/5
20.390	FP	20.390	FP	Simplex	Voice	21	1	BXR A/RIA 330	120	Fair Comm. Intelligible link
20.390	FP	7.355	RWP	Duplex	ISB	21	1	A/RIA 330	120	5/5

TABLE XLIII (Continued)

Tx Freq	Tx Ant	Rx Freq	Rx Ant	Mode	Mode Type	Flt	No. Times	Terminal	Range	Results
10.740	FP	10.740	FP	Simplex	Voice	22	1	BXR A/RIA 375	1300 120	Weak but readable 5/5
7.355	FP	7.355	FP	Simplex	Voice	22	2	BXR A/RIA 375	1300 120	Weak but readable 5/5
6.685	FP	7.355	RWP	Duplex	Voice	22	1	BXR	1300	Weak but readable
5.810	FP	7.355	RWP	Duplex	ISB	22	1	A/RIA 375 BXR	120 1300	5/5 Weak but readable
5.810 6.7135	FP LWP	13.635 10.740	RWP RWP	Duplex Freq Diver.	ISB Sideband Diversity	22	1	A/RIA 375	120	Uncombined 5/5 Combined has echo effect.
10.780	FP	10.780	FP	Simplex	Voice	23	2	Cape	1000	5/5
6.7135	FP	6.7135	FP	Simplex	Voice	23	1	Douglas Dog	120	5/5
10.370	LWP	7.355	RWP	Duplex	ISB	23	1	Cape	1000	5/5
10.740	LWP	7.355	RWP	Duplex	ISB	23	1	Cape	1000	5/5
10.780	TWA	10.780	TWA	Simplex	Voice	24	1 1	Cape Antigua	1000 2200	5/5 1/1
11.176	TWA	11.176	TWA	Simplex	Voice	24	1 1	Andrews AFB Loring AFB	1300 2500	5/5 1/1
10.780	TWA	10.780 20.390	TWA RWP	Simplex Duplex Uplink	Voice TTY	24	1	Cape	1000	5/5
10.780 20.390	TWA LWP	10.780	TWA	Simplex Duplex Downlink	Voice TTY	24	1	Cape	1000	5/5
10.780 9.043	TWA LWP	10.780	TWA	Simplex Duplex	Voice TTY	24	1	Cape	1000	5/5
10.780 7.355	TWA LWP	10.780	TWA	Simplex Duplex	Voice TTY	24	1	Cape	1000	5/5
10.780	TWA	10.780	TWA	Simplex	Voice	25	1	Cape Antigua	1000 2200	3/4 4/4
6.738	TWA	6.738	TWA	Simplex	Voice	25	1	Scott AFB Bellville, Ill.	400	5/5
10.780	TWA	10.780	TWA	Simplex	Voice	25	1	Cape	1000	2/2
6.7135	TWA	6.7135	TWA	Simplex	Voice	25	1	Douglas Dog	120	5/5
10.780	LWP	10.780	LWP	Simplex	Voice	27	1	Cape	100	5/5
7.355	TWA	9.043	RWP	Duplex	ISB	27	1	Cape	200	5/5
7.355 10.780	TWA LWP	9.043 10.780	RWP LWP	Duplex Simplex	ISB Voice	27	1	Cape Cape	400	4 to 5/5
11.407 10.780	TWA LWP	9.043 10.780	RWP LWP	Duplex Simplex	ISB Voice	27	1	Cape	500	5/5
13.878 10.780	TWA LWP	9.043 10.780	RWP LWP	Duplex Simplex	ISB Voice	27		Cape	1300	5/5
13.878 10.780	TWA LWP	12.140 10.780	RWP LWP	Duplex Simplex	ISB Voice	27		Cape	1300	5/5

TABLE XLIII (Continued)

Tx Freq	Tx Ant	Rx Freq	Rx Ant	Mode	Mode Type	Flt	No. Times	Terminal	Range	Results
10.780	LWP	10.780	LWP	Simplex	Voice	28	1	Cape	100	5/5
4.900	LWP	9.043	RWP	Duplex	ISB	28	1	Cape	100	5/5
6.738	TWA		TWA		Voice	28		Ship Rose Knott Victor	3100	5/5
	TWA		TWA				1	Scott AFB Bellville, Ill.	750	5/5
	TWA		TWA				1	Andrews AFB Wash., D. C.	650	5/5
	TWA		TWA				1	Loring AFB Maine	1500	5/5
13.218	TWA	13.218	TWA	Simplex	Voice	28	1	Vandenburg AFB, Calif.	2100	5/5
6.7135	TWA	6.7135	TWA	Simplex	Voice	28	1	Douglas Dog	1100	Weak but readable
10.780	TWA	10.780	TWA	Simplex	Voice	28	1	A/RIA 330 Tulsa	1100	5/5
4.900	LWP	9.043	RWP	Duplex	Voice	28	1	Cape	900	5/5
6.7135	LWP	6.7135	LWP	Simplex	Voice	28	1	Douglas Dog	100	5/5
10.780	TWA	10.780	TWA	Simplex	Voice	28	1	Cape	1140	4/4
13.218	LWP	13.218	LWP	Simplex	Voice	28	1	Vandenburg AFB	1300	5/5
13.218	LWP	13.218	LWP	Simplex	Voice	28	1	Hawaii	3100	1/1 Weak
6.7135	LWP	6.7135	LWP	Simplex	Voice	29	1	Douglas Dog	100	5/5
10.780	LWP	10.780	LWP	Simplex	Voice	29	1	Cape	1100	5/5
7.355	LWP	9.043	RWP	Duplex	Voice	29	1	Cape	1100	5/5 for two voice relays; 4/4 for last voice relay
10.780	LWP	10.780	LWP	Simplex	Voice	30	1	Cape	800	5/5
10.780	TWA	10.780	TWA	Simplex	Voice	30	1	Cape	800	5/5
7.355	TWA & LWP	11.407	RWP	Duplex	Voice	30	1 1	Cape	800	5/5 both antennas
10.780	TWA & LWP	10.780	TWA & LWP	Simplex	Voice	30	1 1	Cape & Antigua	800 2000	5/5, no difference 3/3 clear, no diff
20.390	TWA & LWP	20.390	TWA & LWP	Simplex	Voice	30	1 1	Cape & Ascension	800 5000	4/4 both antennas 2/2 both antennas
13.218	TWA & LWP	13.218	TWA & LWP	Simplex	Voice	30	1 1	Vandenburg	2100	3/3 both antennas
7.355	LWP	11.407	RWP	Duplex	Voice	30	1	Cape	800	5/5
20.390	TWA		TWA		Voice	30		Ascension	5000	3 to 4/4 weak but readable
							1	Pretoria	7800	1/1 very weak
10.780	LWP	10.780	LWP	Simplex	Voice	31	1	Cape	1100	5/5

monitor a specific frequency in a simplex configuration. Excellent communications were established at ranges from 120-nm to 5000-nm.

The trailing wire antenna was utilized for transmit and the right wing probe for receive (duplex) for ranges from 200-nm to 1000-nm, with 5/5 communications. Links evaluated as 5/5 were established simplex with the trailing wire antenna at ranges from 120-nm to 3100-nm. Other contacts made included 4/4 communications at a range of 5000-nm and 1/1 contact with Pretoria, South Africa, at a range of 7800-nm.

During Flight 30, tests were made using the trailing wire and wing probe antennas alternately to contact the same HF terminal. Both antennas appeared to function equally well. No difference in audio level was discernible by the ground operator. Testing of the trailing wire antenna was too limited in scope to derive comparisons to the probes. Limited test time was available owing to mechanical problems in the reel mechanism and drogue attachment which results in drogue loss. A detailed description of problems encountered may be found in Section 3. 8. 7, Design/Operational Problems.

The fin probe was used in a simplex configuration and 5/5 communication links were established at ranges from 120-nm to 5500-nm. Duplex links were established several times utilizing the fin probe for transmit and right wing probe for receive. No interference was noted and 5/5 communications were established. The fin probe was used as the receive antenna while transmitting from both wing probes on Flight 20 and interference was noted on the receivers. The system was repatched to transmit from the left wing probe and fin probe and receive with the right wing probe; no interference was noted after repatching. Frequencies being used were 10. 740 and 13. 635 MHz for transmit and 6. 685 MHz for receive.

The interference noted when receiving on the fin probe has been isolated to faulty static dischargers and the presence of a 100 foot trailing cone which had been installed on the tail. The trailing cone was removed prior to Flight 24. No interference was detected on later flights using this configuration (fin probe for receive, right wing probe, and left wing probe for transmit) on various frequencies.

In conclusion, all HF antennas were tested and operated satisfactorily on all frequencies. No interference or incompatibility exists between antennas in any configuration tested. Sufficient test data has not been accumulated to conclusively determine the advantage, if any, of the trailing wire antennas over the other three antennas.

3. 8. 5. 7 System Performance —— Test 7

Establish teletype communications using a pre-programmed tape from the typing reperforator, the keyboard send/receive unit, or both.

Goal

A maximum of one error in each "Quick Brown Fox" (QBF) message.

Conditions

These tests were performed throughout Category II testing; a pre-programmed tape was normally used to transmit continuous QBF messages. Non-diversity, two-tone, and four-tone diversity tests were performed to evaluate the advantages of using tone diversity. Where non-diversity and dual diversity modes proved less reliable than quad diversity, only quad diversity results are shown. Error counts are averaged for the number of lines sent in a particular message, i.e., if 100 lines were sent, the total number of errors were divided by 100 to establish the average errors per line. Doppler correction was used on all tests, therefore, an additional 425 Hz tone was transmitted simultaneously with the FSK tone (or tones).

Test Results

Table XLIV lists the results of teletype tests using a pre-programmed tape.

The goal of one or less errors per line was met on TTY communications during eight flights. Readable teletype communications were established on all flights on which TTY communications were attempted. Although teletype communications were established and maintained during periods when the A/RIA was acquiring and tracking, receiving and recording TLM data and relaying voice, no TTY operations interfered with other functions, or vice versa.

3.8.5.8 System Performance —— Test 8

Demonstrate single, dual and quad tone diversity teletype operation.

Goal

Demonstrate improvement caused by tone diversity operation.

Conditions

Tests were conducted at various frequencies with a ground-based A/RIA, the A/RIA mock-up at Bendix Radio (Baltimore) and Cape Kennedy. Single, twin, and quad tone diversity were used.

Once a TTY link was established, a message was sent for several minutes in each diversity mode. Errors were counted as follows:

a. A missed character as one error.

b. Printing letters rather than numbers as one error.

c. Improper spacing at the beginning of a line or between lines as one error.

d. Where a message was completely unreadable, the number of lines listed in the test results is estimated.

TABLE XLIV

Teletype Test Results

Side Band	Tx Freq	Rx Freq	Terminal	Flt	WPM	Tone Channels	Tone Diversity	Results
B2	6.685	3.116	A/RIA 330	10	100	4,6,8,10	Quad	17 lines/1 error
						4, 10	Dual	17 lines/1 error
						10	Single	17 lines/3 errors
						10	Single	17 lines/no errors
								Total of 68 lines/5 errors.
								No TTY received because of
								Mission Abort.
A2	6.685		A/RIA 330	11	100	4,6,8,10	Quad	17 lines/1 error
A2		6.685		11	100	4,6,8,10	Quad	7 lines/3 errors -
								.42 errors/line
A2	20.475		BXR	14	100	4,6,8,10	Quad	10 lines/9 errors
A2		20.475	BXR	14	100	4,6,8,10	Quad	6 lines/3 errors
A2	20.475		BXR	14	100	4,6,8,10	Quad	68 lines/58 errors
A2		20.475	BXR	14	100	4,6,8,10	Quad	58 lines/18 errors
								During the test measured
								-25 cps doppler correction
								at Bendix Radio, Baltimore.
A2	20.475		BXR	14	100	4,6,8,10	Quad	107 lines/63 errors
A2	14.553	20.475	BXR	14	100	4,6,8,10	Quad	Transmitted - 46 lines/17 error
								Received - 46 lines/6 errors
B1	14.553		A/RIA 375	16	60	4,6,8,10	Quad	49 lines/2 errors
								Measured doppler shift
								+10 cps inbound, -8 cps outbound
A2	20.475	6.685	A/RIA 375	18	100	4,6,8,10	Quad	Not Evaluated
B1		6.685	A/RIA 375	20	100	4,6,8,10	Quad	80 lines/151 errors received
	10.740							
B1		6.685	A/RIA 375	20	100	4,6,8,10	Quad	340 lines/609 errors received
	13.635							
								Total of 420 lines
								1.8 errors/line
B1	20.390		A/RIA 330	21	100	4	Single	14 lines/no errors
						4,6,8,10	Quad	16 lines/no errors
	7.355					4	Single	22 lines/99 errors
								4.5 errors/line
						4,6	Dual	18 lines/5 errors

TABLE XLIV (Continued)

Mode Band	Tx Freq	Rx Freq	Terminal	Flt	WPM	Tone Channels	Tone Diversity	Results
A2		7.355	BXR	22		4,6,8,10	Quad	70 lines/133 errors
						4	Single	25 lines/unreadable
						4,6	Dual	30 lines/unreadable
						4,6,8,10	Quad	40 lines/unreadable
A2		10.740	A/RIA 375	22		4	Single	12 lines/5 errors
						4,6	Dual	14 lines/38 errors
						4,6,8,10	Quad	16 lines/5 errors
B2	5.810		A/RIA 375	22		4	Single	Almost unreadable
								3 lines/30 errors
								9 lines sent/6 unreadable
						4,6	Dual	9 lines/no errors
						4,6,8,10	Quad	12 lines/no errors
B2	5.810		A/RIA 375	22		4	Single	30 lines/unreadable
						4,6	Dual	12 lines/6 errors
						4,6,8,10	Quad	20 lines/7 errors
B1		7.355	Cape	23	100	7,8,9,10	Quad	112 lines/132 errors 1.1 errors/line
		7.355				7,8	Dual	358 lines/1089 errors 3.0 errors/line
B1		20.390	Cape	24	100	7	Single	79 lines/393 errors 4.9 errors/line
B1		20.390	Cape	24	100	7 & 8	Twin	55 lines/80 errors
						9 & 10	Twin	55 lines/114 errors
B1		20.390	Cape	24	100	7,8,9,10	Quad	69 lines/82 errors
B1	9.043		Cape	24	100	7 & 8	Twin	90 lines/269 errors
						9 & 10	Twin	136 lines/345 errors
B1	7.355		Cape	24	100	7 & 8	Twin	42 lines/57 errors
						9 & 10	Twin	42 lines/34 errors
B1	4.900	9.043	Cape	27	100	7,8,9,10	Twin	90 to 100% copy with doppler shift up to +15 cps. No interference noted during Acquisition, Tracking of a Ballistic Missile. Error Count not possible because of lack of data from Cape.
A1		9.043	Cape	28	100	7	Single	110 lines/39 errors
A1	4.900					7,8,9,10	Twin	No results from Cape
A1		9.043	Cape	28	100	7 & 8	Twin	176 lines/51 errors
						9 & 10	Twin	282 lines/114 errors. Of the 282 lines, 229 had only 23 errors; on Channels 7 & 8 134 lines had 14 of the total errors.
								Measured doppler shift up to -6 cps.

Test Results

The results of TTY tone diversity tests are shown in Table XLV.

The results from Flight 10 tests are inconclusive, since the single-tone message showed less errors than messages sent by dual and quad diversity. The messages transmitted from A/RIA 372 during Flight 21 were received at A/RIA 330 with no errors using single or quad diversity. The messages received at A/RIA 372 showed a definite improvement when dual diversity was used rather than a single tone. The average number of errors dropped from 4.5 to .27 errors per line.

On Flight 22, tests with Bendix Radio (Baltimore) were inconclusive. On this same flight messages received from A/RIA 375 appeared to show an improvement when receiving quad diversity. The messages transmitted to A/RIA 375 showed a definite improvement when dual and quad diversity were used. Quad tone diversity yielded a definite improvement over dual tone diversity during Flight 23.

Tests during Flight 24 also yielded conclusive results. Messages received via twin diversity on two separate page printers showed an improvement over messages received on a single tone, and messages received on four tone diversity had fewer errors per line than the messages received on twin diversity.

Twin diversity messages again yielded an improvement over non-diversity messages on Flight 28. Table XLV shows a reduction in errors per line for Channels 7 and 8 and an increase for Channels 9 and 10, compared to Channel 7; however, messages received on these four channels experienced an apparent frequency fade for a portion of the test. Of the 282 lines received on Channels 9 and 10, 229 had a total of 23 errors (.1 errors/line). Of the 176 lines received on Channels 7 and 8, 134 of them had only 14 errors (.1 errors/line).

The test results prove that dual or twin diversity operation is preferred over non-diversity operation. Further, some improvement over two-tone diversity can be expected when four tones are used. Based upon test results, quad diversity operation is recommended for normal operation. Twin diversity adds versatility to the system by providing the capability to send two messages simultaneously on one TTY link.

The test goal was successfully met, since results show that tone diversity operation yields better TTY than single tone operation.

3.8.5.9 System Performance —— Test 9

Send and receive teletype messages using doppler correction tone.

Goal

Demonstrate teletype communications with one or less errors per line in the presence of doppler shift.

TABLE XLV

Teletype Tone Diversity Test Results

Tx Freq	Rx Freq	Terminal	Range	Flt	Tone Channels	Tone Diversity	RESULTS Lines	Errors	Average Errors/Line
6.685		A/RIA 330	120	10	4,6,8,10	Quad	17	1	.058
					4,10	Dual	17	1	.058
					10	Single	17	3	.11
					10	Single	17	0	0
20.390		A/RIA 330	120	21	4	Single	14	0	0
					4,6,8,10	Quad	16	0	0
	7.355		120	21	4	Single	22	99	4.5
					4,6	Dual	18	5	.27
	7.355	BXR	1300	22	4,6,8,10	Quad	70	133	1.9
					4	Single	25	Unreadable	
					4,6	Dual	25	Unreadable	
					4,6,8,10	Quad	40	Unreadable	
	10.740	A/RIA 375	120	22	4	Single	12	5	.41
					4,6	Dual	14	38	2.7
					4,6,8,10	Quad	16	5	.31
5.810		A/RIA 375	120	22	4	Single	9	3 lines 30 errors	6 lines almost unreadable 3 lines averaged 10 errors/line
					4,6	Dual	9	0	0
					4,6,8,10	Quad	12	0	0
5.810		A/RIA 375	120	22	4	Single	30	Unreadable	
					4,6	Dual	12	6	.5
					4,6,8,10	Quad	20	7	.35
	7.355	Cape Kennedy	1000	23	7,8	Dual	358	1089	3.0
					7,8,9,10	Quad	112	132	1.1
	20.390	Cape Kennedy	1000	24	7	Single	79	393	4.9
					7,8	Twin	55	80	1.45
					9,10	Twin	55	114	2.07
					7,8,9,10	Quad	69	82	1.18
	9.043	Cape Kennedy	1000	28	7	Single	110	39	.35
					7,8	Twin	176	51	.28
					9,10	Twin	282	114	.40

Conditions

Doppler correction voltages were fed to the doppler oscillator and measured with a VTVM. The doppler error was calibrated by putting known frequencies from 375 to 475 Hz into the doppler amplifier; voltages measured in-flight were converted to doppler error in Hertz.

Test Results

The results of tests run under conditions of doppler shift are shown in Table XLVI.

TABLE XLVI

Teletype Doppler Correction Test Results

Freq	Terminal	Range N.M.	Tone Channels	Tone Diversity	RESULTS # Lines	# Errors	Avg # Errors	Doppler Shift
20.475	BXR	1000	4,6,8,10	Quad	58	18	.31	-25 cps
14.553	A/RIA 375	120	4,6,8,10	Quad	49	2	.04	+10 inbound -8 outbound
4.900	Cape Kennedy	1300	7,8,9,10	Twin	90 to 100% copy at both terminals			+4 to +15 cps
9.043	Cape Kennedy	900	7, 8 9 & 10	Twin Twin	176 282	51 114	.28 .40	-6 cps

A doppler shift of -25 Hz was measured at Bendix Radio while receiving messages from A/RIA 372 with an average of .31 errors per line. A doppler shift of 25 Hz would have caused a significant number of errors had not doppler correction circuitry been employed.

Doppler shift measurements were made while flying a racetrack pattern near Tulsa. A shift of plus 10 Hz was measured on the inbound run and a negative 8-Hz was measured on the outbound run. The shift went to zero at each end of the racetrack pattern.

The Cape performed doppler shift measurements during a teletype test, with the test aircraft on an inbound run from Antigua. AFETR Engineering reported that the shift varied from plus 4 Hz to plus 15 Hz. AFETR commented that a 4-Hz shift would be insignificant to teletype equipment, but that 15 Hz of shift would be enough to create

numerous errors without doppler correction. A doppler shift of negative 6-Hz was measured on Flight 28 while the aircraft was enroute to Tulsa from Cape Kennedy.

These test results show that the expected improvement of TTY using doppler correction is realized. The A/RIA cannot be configured to bypass the doppler correction circuitry, so a comparison of operation with and without correction was not possible.

3.8.5.10 System Performance —— Test 10

Use and evaluate as many receive/transmit modes and equipment combinations as possible.

Goal

Evaluate HF equipment operability.

Conditions

The system was operated utilizing various receive/transmit modes and equipment combinations with HF ground terminals throughout the test program. Table XLVII, HF Test Matrix, shows equipment usage and operating modes versus flight number for the test flights. The number of times each function was performed is shown on the test matrix. These numbers were derived as follows:

a. Initial establishment of a link is counted.

b. An additional link is counted each time the mode, configuration, or frequency is changed.

c. An additional link is counted if the terminal contacted is changed.

All on-board HF equipment was used during the program. Tests 1 through 9 in this section outline the various modes, configurations, and frequencies employed on the 26 Category II flights, while Table XLVII tabulates the overall use of hardware. A discussion of equipment failures is included in Section 3.8.6.

3.8.5.11 System Performance —— Test 11

Evaluate the effect on HF noise level caused by the engines, basic C-135 equipment, and PMEE.

Goal

Demonstrate that HF receiver noise is unaffected by any aircraft or PMEE operations on the ground or in flight.

TABLE XLVII
HF Test Matrix

Configuratic Function Tested	Flight No. mber of Times Performed																										
	3	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Transmit on Sideband A1	1	3	2	2	1	3	3	2	3		5	2	2	5	4	9	7	7	2	8	6		10	14	3	13	1
A2								1			4		1	2													
B1			1		4	3		2					1	4	3	2	1		3	2			1	1			1
B2							1						1				1	2									
Transmitter No. 1	1	3	2		5	4	3		3			2							2	8	6		5			11	
2				2		4					5		3	5	4	5	8	7	3	2			5	14	3	2	2
3								2						4	3	4		1									
Receive on Sideband A1	1	3	2	2	1	3	3	2	3		6	2	2	5	7	9	7	7	2	8	6		10	15	3	13	1
A2								1			3		1	2													
B1			1		4	4		2	1				1	4		2		2	5	3			1	1			1
B2							1						1				1										
Receiver No. 1	1	3	2	2	5	4	3		3		4	1				4	1		4	11	6		5				
2						2						1	2	5	4	5	7	4	3				5	14	3	13	2
3								2			2		1		3			3									
Transmit on LWP	1	3	2	2	5		3		3		5	2	3	5	4	5	1	1	2				5	6	3	6	2
RWP																1				1							
TWA						4		2												8	6		5	8		7	
FP						2								4	3	3	7	7	3								
Receive on LWP					1				3		4	1	2		1	1	1						5	4	2	4	2
RWP	1	3	2	2	4	4	3	1			2	1	1	5	3	3	1	4	2		6		5	2	1	3	
TWA								1												8				8		6	
FP						2										1	6	3	3	1							
Transmit ISB			1				2	1			4	1	1	4		4		2	2				5	1			
Transmit Freq Diversity															3	4		1					1				
Transmit Sideband Diversity								2					1														
Receive ISB							2	1			4	1	1	4		4	1	2	2				5	1			
Receive Freq Diversity															2			1					1				
Receive Sideband Diversity								2	1				1														
Operate Simplex					1	2		1	3		3	1	2		1	1	7	3	3	8	5		5	13	2	10	2
Operate Duplex	1	3	2	2	4	4	3	1			1	1	1	5	3	4	1	3	2	4			5	1	1	3	
Operate Simplex-Duplex											1																
Demonstrate 2000 NM Range		1																		2				3		8	
Use Combiner #1									1			1							1				1				
#2															3	1		1	1				1				
#3								1					1				1										
TTY 60 wpm													1														
TTY 100 wpm			1			1	1	1			4		1	2		2	1	2	2	5			1	1			
Transmit Non-Diversity			1				2										1	2									
Receive Non-Diversity			1														1	2		1				1			
Transmit Two-Tone Diversity			1				1											2		4				2			
Receive Two-Tone Diversity			1														1	2	1	2			2	2			
Transmit 4-Tone Diversity							1	1			4		1	2		2	1	2					1				
Receive 4-Tone Diversity						1		1			3		1	2		2		3	1	1							
Measure Doppler Correction - Evaluate											1		1										1	1			

Conditions

Prior to starting the engines, the HF equipment was turned on using ground power. The noise levels on sideband A1 and B1 were measured at the following frequencies: 6.685 MHz, 14.553 MHz, and 20.475 MHz. Immediately after the noise level was taken, ground power was removed and the engines were started. After engine start, the HF receivers were turned on and a noise level taken using aircraft power. The instrumentation equipment was on at this time. Noise level was measured after the main air conditioning blower was started. After takeoff measurements were repeated after the PMEE was turned on.

Test Results

The results of the HF noise test are shown in Table XLVIII.

3.8.5.12 System Performance —— Tests not Performed

The tests listed below were planned but not performed, for the reasons given:

Test Measure HF VSWR during flight.

Requirement Source SS100000, Paragraph 4.2.1.1.2.2.2.1

Explanation Quantitative HF VSWR measurements were not taken in flight because they properly belong in the ground test function. The equipment in the airplane is configured for go/no-go; i.e., fault circuits which disable the transmitter when the VSWR on output is greater than 1.3:1.0 (or when the output impedance is other than 50 to 52 ohms). A qualitative functional evaluation has been made of the fault circuits.

Test Measure HF receive and transmit frequency stability in-flight.

Requirement Source SS100000, Paragraph 4.2.1.1.2.2.2.1

Explanation This test was not performed because it was determined to be a ground test properly performed in Category I. Since variables can be controlled and precise measurements can be made on the ground, airborne testing was redundant and validity was doubtful.

3.8.6 Functional Reliability/Operability

HF communications were established on 25 of the 26 flights without difficulty. On Flight 15 communications were not possible until a defective receiver patch cord was replaced. Although many equipment failures occurred during the program, adequate versatility and redundancy is provided to maintain communications. The component with the highest failure rate was the trailing wire antenna. This problem is discussed in detail under Design/Operational Problems following this section.

TABLE XLVIII

HF Noise Test Results

Test Conditions	Test Results
1. Ground power HF equipment only	Noise level measured from -6 dBm to -8 dBm on three frequencies - both sidebands.
2. Aircraft power HF equipment and instrumentation	No significant change in noise level.
3. Aircraft power HF, instrumentation and air conditioning blowers on	No significant change in noise level.
4. In-flight HF, PMEE, blowers, and instrumentation	Appeared to be from 1 to 6 dB decrease in noise on 6.685 and 14.553 MHz, and a 4 to 6-dB increase in noise on 20.475 MHz.
5. In-flight HF, PMEE, blowers and instrumentation The HF transmitters were transmitting into the probes with 10-percent frequency separation between transmitters and receivers.	Measured same levels as in Step 4.

The test goal was successfully achieved. No correlation was noted between the groups of equipments operating and the HF noise level.

Table XLIX lists the total number of HF equipment failures and problems experienced and reported during the Category II test flights. They are tabulated by flight number.

TABLE XLIX

HF System Malfunctions

Flight	Failure/Problem	Corrective Action
3	HF receiver noise energized voice operated relay and keyed uplink VHF transmitter.	Readjusted voice operated relay for less sensitivity.
5	HF receivers 2 and 3 defective.	Airflow interlock would not allow receivers 2 and 3 to operate. Airflow interlock vane was jammed, indicating false condition of no airflow. Replaced vane.
7	HF power amplifier 1 output power fluctuations. It would not tune into coupler.	Caused by 100 KHz reference amplitude fluctuations. Adjusted 100 KHz reference.
	Instrumentation caused interference at 10. 780 and 17. 552 MHz in the HF receivers.	Caused by IRIG code being fed from timing subsystem to oscillograph recorders. Problem corrected by placing filters in the line between timing subsystem and oscillograph.
	HF transmitters would not tune into fin probe.	Incorrect operating procedure was used. Revised procedure.
8	Fin probe would not tune up on PMEE HF transmitter.	Changed tuning unit control.
	Lost trailing wire antenna drogue.	N O T E 1
10	Trailing wire antenna would not extend.	Removed trailing wire and reinstalled without drogue.
	HF receivers 2 and 3 had high noise level.	Receiver sensitivity misaligned.
11	HF signal generator inoperative	Replaced blown fuse.
	Lost channel B1 on HF receiver	Replaced audio amplifier.
12	Trailing wire antenna would not load.	Unknown
13	Trailing wire antenna would not load.	Replaced antenna control coupler.
	Right wing probe failed.	Unknown.

TABLE XLIX (Continued)

Flight	Failure/Problem	Corrective Action
14	Trailing wire antenna extend/ retract operation intermittent.	NOTE 1
15	Lost trailing wire antenna drogue.	NOTE 1
	Could not establish communications during early part of flight.	Replaced receiver patch cable
18	Lost training wire antenna drogue.	NOTE 1
	Transmitter will not tune in in 17 MHz range.	Replaced RF tuner module.
19	System will not copy teletype while airborne; will not properly correct for doppler shift.	Replaced doppler oscillator module.
20	Noted interference when receiving on fin probe and transmitting from wing probes.	Isolated to faulty static dischargers and the presence of a 100 ft. trailing cone which had been installed on the tail. Removed cone.
21	HF receivers 1 and 2 have improper AGC operation on low signal levels.	Receiver alignment.

NOTE 1: The trailing wire mechanical malfunctions are discussed in Section 3.13.

3.8.7 Design/Operational Problems

3.8.7.1 HF Voice Combiner Will Not Combine Frequency Diversity or Sideband Diversity Signals

Problem

Tests have shown that the HF voice combiner will not satisfactorily combine frequency diversity or sideband diversity signals. The combined audio suffered output fluctuations and had a pronounced echo effect. The problem has been determined to be caused by a lack of frequency coherence of the received signals.

Recommendation

Sideband diversity combining could be accomplished by having the transmitting station send a pilot carrier with the SSB. If this solution is not possible, it is recommended that the HF combiner be replaced by a diversity selector. A selector would provide protection against short-term frequency fades, and would also permit frequency diversity reception. The theoretical SNR improvement gained by a combiner is substantially undetectable by the human ear.

3.9 DATA DUMP

Test Result Summary

Data were dumped successfully on two separate missions. First, VHF (P-Band 237.8 MHz) data were dumped after Gemini XII Orbits 44 and 45 to the Corpus Christi station for a functional and qualitative evaluation. On the second mission, P-Band and S-Band (2287.5 MHz) data were dumped simultaneously to the TEL IV station at Cape Kennedy under controlled conditions for quantitative test results. The dumped data were found equal to those on the recorded tapes in the A/RIA. Horizontal plane radiation patterns were derived for both frequencies. The P-Band in-flight and model study patterns were found to be in good agreement. Problems with TEL IV S-Band tracking caused the S-Band data to be somewhat scattered such that a horizontal plane pattern was derived that was representative only. Both patterns showed gain greater than an isotropic radiator in all azimuthal areas forward of the wings and shadowing effects in the aft areas. The flight pattern recommended for both antennas is an inbound radial to the receiving station to take advantage of the greater gain margins. The derived antenna patterns show that the maximum range for both frequencies can be as great as the radio horizon; however, the actual range is dependent on the receiving station characteristics and propagation properties during the transmission period.

Data dump of the unified S-Band 1.024 MHz subcarrier was not attempted because ground tests had shown that the wideband recorder was not capable of this task.

3.9.1 Tests Performed

Test 1 Dump Gemini data at VHF (P-Band 237.8 MHz) to Corpus Christi after Gemini Orbits 44 and 45.

Test 2 Dump prerecorded Apollo format 51.2 KBPS data to TEL IV - ETR at VHF to determine data dump range (Category II Flight Test Procedure, Paragraph 7.10.1.C.1).

Test 3 VHF data dump antenna radiation pattern checks. Determine antenna patterns and preferred flight pattern (Category II Flight Test Procedure, Paragraph 7.10.1.C.2).

Test 4 Dump prerecorded Apollo format 51.2 KBPS data to TEL IV - ETR at UHF (S-Band 2287.5 MHz) to determine data dump range (Category II Flight Test Procedure, Paragraph 7.10.2.C.1).

Test 5 UHF data dump antenna radiation pattern checks. Determine antenna patterns and preferred flight pattern (Category II Flight Test Procedure, Paragraph 7.10.2.C.2).

3.9.2 Test Environment

VHF data dump tests were performed with Corpus Christi (during Gemini) and TEL IV ETR (Flight 28). These are tracking stations equipped to receive, record, and analyze the dumped data.

The data dump to Corpus Christi was accomplished on an inbound radial to the station. Since no quantitative data were desired on this test, no description of the Corpus Christi facility is presented in this report.

The routine data dump to TEL IV ETR was performed on an inbound radial as shown in Flight Plan I, Figure 84. The A/RIA began the inbound run approximately 240-nm from the station, transmitting carrier-only on VHF and UHF simultaneously. When TEL IV reported a solid signal acquisition (200-nm on VHF), the wideband recorder was started in playback, modulating the carriers with a 51.2-KBPS bit stream to the Apollo format. The test was terminated at approximately 70-nm.

The data dump antenna horizontal plane pattern checks were performed with the A/RIA flying the pattern shown in Flight Plan II, Figure 84. After completing the inbound radial, the aircraft flew back to Point 4 on the pattern and began to fly the circle shown in Figure 84. Two circular patterns were flown, both transmitting the 51.2-KBPS bit stream simultaneously on VHF and UHF.

A simplified block diagram of the TEL IV ground station is shown in Figure 85. Signal strength recordings were made from both the RHC and LHC receivers on VHF and from the LHC on UHF. Bit error counts were derived from each frequency. All

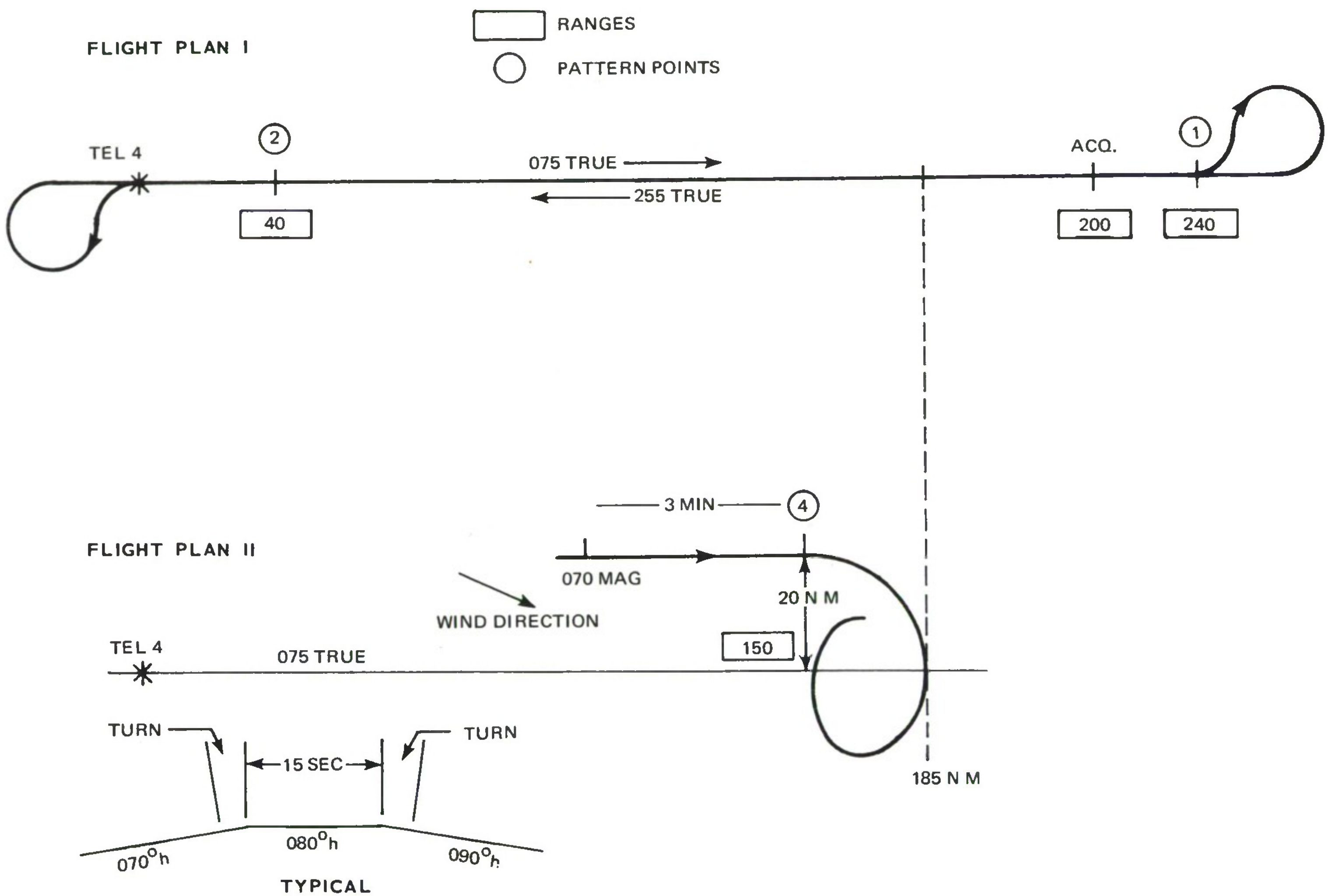


FIGURE 84. DATA DUMP TEST FLIGHT PATTERNS

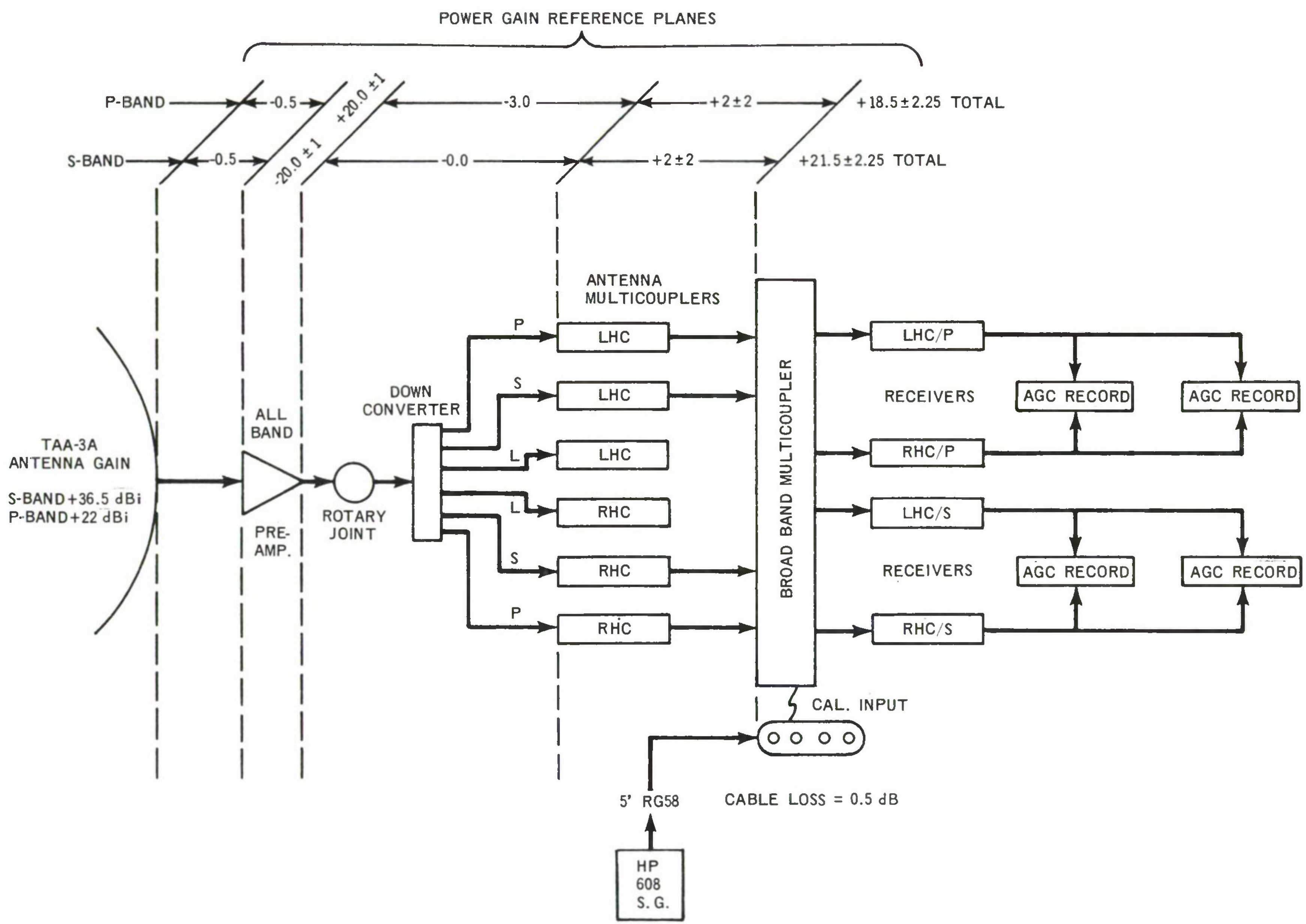


FIGURE 85. TEL-IV SIMPLIFIED BLOCK DIAGRAM

significant TEL IV parameters used for deriving signal strengths are annotated on Figure 85.

3.9.3 Data Collection/Reduction Techniques

The data collected for use in deriving test results included flight logs, TEL IV AGC recordings, TEL IV observer's reports, and X-Y radar plots of the A/RIA aircraft track. The TEL IV recorder calibrations in microvolts were converted to decibels below a milliwatt (-dBm) where -107 dBm = 1 μ volt across a 50-ohm load. These levels were referenced to the TEL IV antenna load by the following:

P-Band			S-Band	
-107.0 dBm		1-μ volt at RCVR	-107.0 dBm	
- 18.5	$\pm$ 2.25 dB	Internal system gain (rss)	- 21.5	$\pm$ 2.25 dB
- 0.5 dB		Calibration cable loss	- 0.5 dB	
-126.0	$\pm$ 2.25 dBm	1-μ volt at antenna terminals	-129.0	$\pm$ 2.25 dB

NOTE: The $\pm$ 2.25-dB system gain tolerance has an effect on absolute values, but should have remained static during the test period so that relative values were unaffected.

To obtain the isotropic level for the test parameters, the classical one-way equation was used:

$$P_{rant} = (G_r - L_s) + (P_t - L_t) - (37.8 + 20 \log f_{mc} + 20 \log R_{nm}), \text{ Decibels} \quad \text{(EQ 9.1)}$$

Where

P_{rant} = Signal level at the receiving antenna terminals

G_r = Gain of receiving antenna

P_t = Transmitter output

L_t = Transmission system line losses

L_s = Scan loss of receiving antenna (unknown, but assumed to be 0.0 dB for P-Band. By inspection, the S-Band scan was variable, and the peaks were used as absolute values.)

The isotropic levels for the two systems at 100-nm are shown below:

P-Band		S-Band
+22.0 dB	(1) G_r	+ 36.5 dB
+27.0 dBm	P_t	+ 27.0 dBm
- 1.2 dB	L_t	- 1.2 dB
-85.3 dB	37.8 + 20 log F_{mc}	-105.0 dB
-37.5 dBm		- 43.7 dBm
-40.0 dB	20 log R_{nm} at 100 nm	- 40.0 dB
-77.5 dBm	P_{rant} with $G_{t_{iso}}$	- 82.7 dB

(1) The polarization loss is included in the cited gains for the TEL IV antenna. (The aircraft antenna was vertically polarized, and the TEL IV had nominal RHC and LHC polarizations.)

A standard technique was used to convert the measured signal levels to normalized field intensities E(MV/M/W at 1 mile) as functions of vertical (Θ) or azimuth ($\emptyset$) angles.

a. Received signal levels (P_{rant}) at the antenna load obtained during an inbound run were plotted versus slant range on semi-log paper. The isotropic level was derived by the standard range equation (EQ 9.1). This 6 dB/range-octave was also drawn on the same plot to reference antenna gain in dBi.

b. The gains in decibels referenced to an isotropic (dBi) were converted to normalized field intensities by the equation:

$$\text{dBi} = 20 \log \frac{(E\quad)}{(3.4\ )} \qquad \text{(EQ 9.2)}$$

c. The azimuthal angles ($\emptyset$) were derived from the aircraft true headings and true bearings from TEL IV.

d. The vertical angles (θ) were derived from the range and aircraft altitude. The 3.5-degree nose-up flight attitude was included.

The physical and propagational characteristics of TEL IV placed significant analytical constraints on the quality of the S-Band test results. (There was little effect on the P-Band results.) These characteristics, which were not known until after the records were analyzed, are shown below.

a. The servo limits of the TEL IV tracking antenna were mechanically limited at 1 degree above the horizon. With a standard 4/3rds earth, auto tracking with S-Band would be limited to 160-nm range. Beyond this range, the circular scan of the antenna would move progressively above the target. In actuality, the records showed that smooth S-Band track degraded rapidly beyond 140-nm, indicating non-standard propagation and manual S-Band track beyond that range.

b. The normal minimum - maximum signal envelope during auto-track with this type of scanning antenna is < 3 dB. Test record measurements showed the average scan envelope to be 6 dB with excursions to 10 dB during track at ranges less than 100-nm. During the segmented circle patterns (ranges of 155 to 185-nm), the differences exceeded 18 dB at some points. This extreme roll-off, far in excess of the norm, indicated tracking problems inherent to the TEL IV site.

c. The ellipticity of the TEL IV antenna pattern was indicated by the disparities between the right-hand and left-hand circular channel recordings and the 4 to 6-dB scan modulation.

d. The TEL IV RHC channel AGC had a continuous baseline shift of 4 to 6 dB. The absolute values of the calibrations then became academic and useful only as reference.

e. The TEL IV LHC channel AGC indicated a noise increase that limited AGC action to a signal of approximately -114 dBm.

After the above characteristics were analyzed, a close examination was made of the signal environment in which the circle patterns were flown. Simultaneous readouts of signal levels for both frequencies on the same inbound run (taken in 10-second increments) indicated that there was some variation in the P-Band level and very sharp variations in the S-Band levels. Inspection of the datum records showed that the variations were inherent to the TEL IV station characteristics and the actual test conditions. The basic problem was that the TEL IV antenna could not auto-track below 1 degree above the horizon, and the personnel had some difficulty in retaining the aircraft in the UHF antenna boresight in both azimuth and elevation. Apparently, the VHF signal was used for the majority of tracking. To approximate the beam widths of the TAA-3A antenna, the following equation is used for rotational parabolas.

$$\text{Beam width, between nulls, in degrees} = 137.5/(D/\lambda) \qquad \text{(EQ 9. 3)}$$

Where D/λ is the mouth diameter in wave lengths.

This yields

BW^{o}_{p} 19.0^{o} and BW^{o}_{s} 2.0^{o}

Thus, the UHF signal roll-off became significant with a 1-degree tracking error, and the VHF roll-off was not discernible until the tracking error exceeded 6 degrees. With this information, the analyst could determine for P-Band what areas represented propagation anomalies and the areas that represented tracking difficulties. Therefore, the P-Band horizontal plane pattern was relatively easy to derive and is representative of the true pattern $\pm$ 2.25 dB (TEL IV system tolerance) $\pm$ 1.5 dB (estimated readout and analytical error). The following procedure was used:

a. At each aircraft heading, the received signal level was referenced to the level received off the nose for that point in range.

b. Since the signal level off the nose of the aircraft was established in gain over an isotropic radiator, the level from each azimuthal point could be referenced to the isotropic level.

c. Gain (or loss) in dBi was then converted to field intensities by Equation 9.2 and plotted in Figure 90.

The S-Band horizontal plane pattern presented serious problems. The steep gradients of the signal levels obtained during the inbound radial, considered with the narrow beam of the receiving antenna, pointed to tracking error as the main fault. This, of course, could not have been expected to have been repeatable during the circle flight patterns; thus, the technique used for the P-Band pattern could not be used for S-Band. To derive a representative S-Band pattern, the following steps were taken:

a. The signal strength off the nose (during the circle pattern) was measured and was arbitrarily assumed to be 5 dBi. (The laboratory radiation study shows this 5-dBi gain at the in-flight elevation angle.)

b. Each azimuthal point was referenced to the signal off the nose and then was adjusted for the actual range differential.

c. With the antenna mounted in the center of the bottom fuselage, the pattern could be considered reasonably symmetrical; so the signal levels at the mirror points on each side of the aircraft were compared and averaged.

d. Each median value was plotted in uV/M/W at 1 mile, at the averaged mirror azimuthal point in Figure 93.

The bits-in-error were derived from a computer strip-out of the magnetic tape recorded during the test. The count was made by comparing the sync word in each frame with the known sync word, and the bits-in-error for each 500 frames were printed out. This was correlated to range by GMT time.

3.9.4 System Configuration

3.9.4.1 VHF System Configuration

A block diagram of the VHF data dump system during the Gemini data dump test is shown in Figure 86.

During the Gemini data dump test, predetected data from the tape were fed to the predetection playback monitor, where they were converted to 10 MHz IF, and fed to the VHF data dump transmitter. The data dump transmitter converted the data to 237.8 MHz and transmitted it to the ground station.

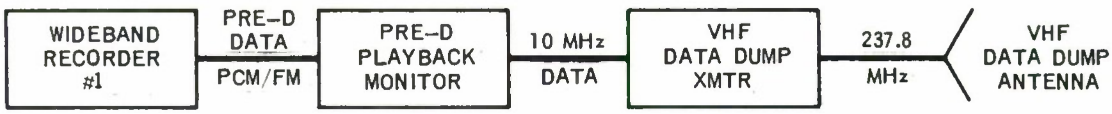


FIGURE 86. BLOCK DIAGRAM - VHF DATA DUMP FOR GEMINI

A block diagram of the VHF Data Dump System during the TEL IV-ETR data dump test is shown in Figure 87.

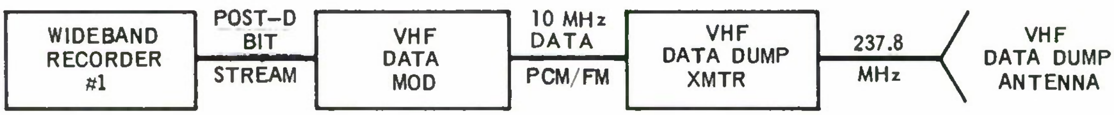


FIGURE 87. BLOCK DIAGRAM - VHF DATA DUMP FOR TEL IV

During the TEL IV-ETR data dump test, a prerecorded tape with a bit stream consisting of 51.2 KBPS CSM Apollo format data was used to modulate the VHF data dump transmitter. The output of the wideband recorder (a post-detected bit stream) was fed to the VHF data modulator, where it was frequency modulated on a 10 MHz IF carrier. The 10 MHz carrier was converted to 237.8 MHz in the VHF data dump transmitter and transmitted to the ground.

3.9.4.2 UHF System Configuration

A block diagram of the UHF data dump system during the TEL IV-ETR data dump test is shown in Figure 88.

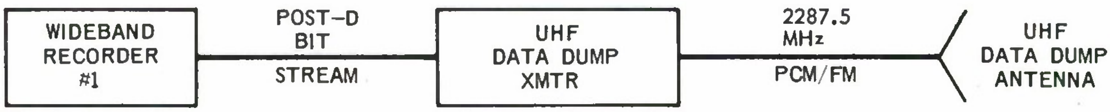


FIGURE 88. BLOCK DIAGRAM - UHF DATA DUMP FOR TEL IV

A prerecorded tape of 51.2 KBPS CSM Apollo format data was used to modulate the UHF transmitter. The carrier frequency was 2287.5 MHz.

3.9.5 System Performance

3.9.5.1 System Performance —— Test 1

Dump Gemini data at VHF to Corpus Christi after Gemini Orbits 44 and 45.

Goal

Dumped data are comparable to those recorded on the tape used to modulate the data dump transmitter.

Conditions

The A/RIA flew an inbound radial to the ground station transmitting an unmodulated carrier. When notified of carrier acquisition by Corpus Christi, the transmitter was modulated with data recorded on the previous Gemini orbit.

Test Results

VHF data were successfully dumped after Orbits 44 and 45. Reports from ETR and Johns Hopkins/APL indicate that the data dumped were comparable to those on the A/RIA tapes. After Orbit 44, 10 minutes of data were dumped, and bit error readouts show 4 minutes of error-free data. Of the 13 minutes of data dumped after Orbit 45, there were 3 minutes of error-free data. No quantitative analysis was made of the above results.

3.9.5.2 System Performance —— Test 2

Dump prerecorded Apollo format 51.2 KBPS data to TEL IV-ETR at VHF to determine data dump range.

Goal

The goal of the test was to determine the maximum range at which A/RIA could dump useful data at VHF to the TEL IV site.

Conditions

The A/RIA flew an inbound radial at 35,000 feet to TEL IV as shown in Figure 84, Flight Plan 1. The data dumped to TEL IV were a 51.2 KBPS bit stream at the Apollo format recorded on a 450 KHz FM subcarrier deviated $\pm$ 30 percent. The prerecorded tape was furnished by ETR to DAC requirements. The VHF carrier frequency was 237.8 MHz. The VHF transmitter power was set to 0.5 watt for these tests. The cable loss from the transmitter to the antenna was measured just prior to the test.

Test Results

The test was successfully performed on Flight 28. Figure 89 is a plot of the signal strength recorded at TEL IV as the aircraft flew an inbound radial from 250-nm to 10-nm range. This plot is an average of the right hand and left hand circular receiving channels. An isotropic radiator reference level is also presented on this plot. A classical propagation pattern, caused by the combined land and water reflection effects, begins at 65-nm and continues through the null at 105-nm with the peak at approximately 140-nm. The signal level rolls off rapidly beyond this point caused by a combination of propagation characteristics and the elevation limits of the TEL IV tracking antenna. From this plot, the true gain of the VHF data dump transmitting antenna can be averaged as 5.5 dBi off the nose of the aircraft with elevation angles from 95^{o} to 115^{o}. A vertical cut appears as Figure 90.

The bits-in-error (BIE/500 frames) counts for the TEL IV VHF, RHC, and LHC channels showed significant differences over the 26-minute transmission period during the inbound radial. The measured signal level in both channels was high enough to produce a minimum of 6 dB SNR in all cases. This suggests that some of the errors were incurred in the receiving equipment. The bits-in-error are summarized below:

Bits-in-Error per 500 Frames		Slant Range
LHC Chan.	RHC Chan.	From TEL IV (nm)
0	14	205 to 200
0	6	200 to 175
6	5	175 to 150
0	0	150 to 125
0	2	125 to 100
3	3	100 to 75
0	2	75 to 62
Totals 9	32	143 nm - 26.11 Minutes

It is concluded, from the preceding results, that the VHF data dump system capability is limited by the radio horizon and the receiving station propagational characteristics. The recommended operational procedure is to fly inbound to the station, with a carrier signal only, until a solid tracking lock and the desired signal level are obtained. At that point the modulated signal may be transmitted and received with minimum drop-out.

3.9.5.3 System Performance —— Test 3

P-Band data dump radiation pattern checks.

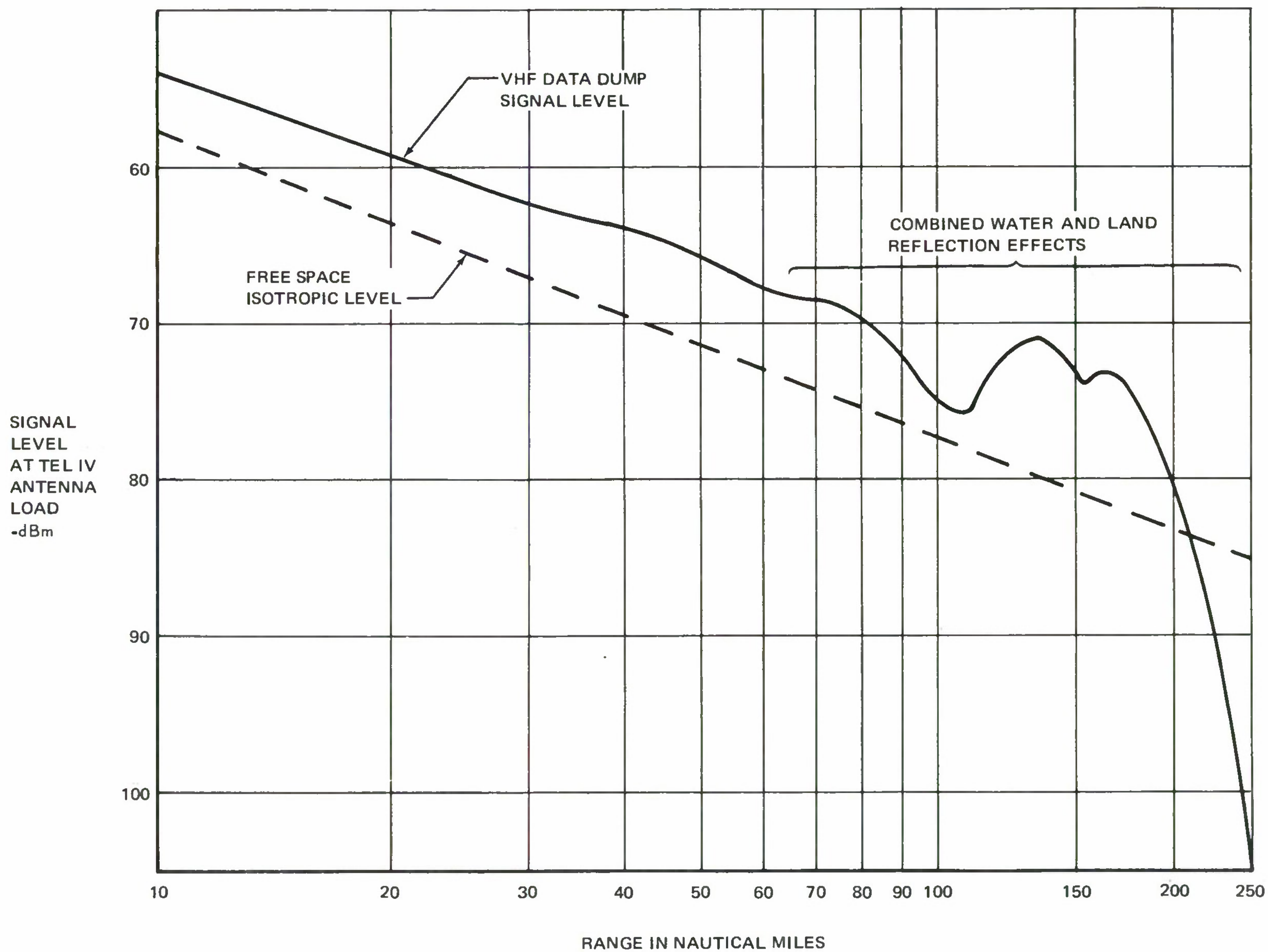
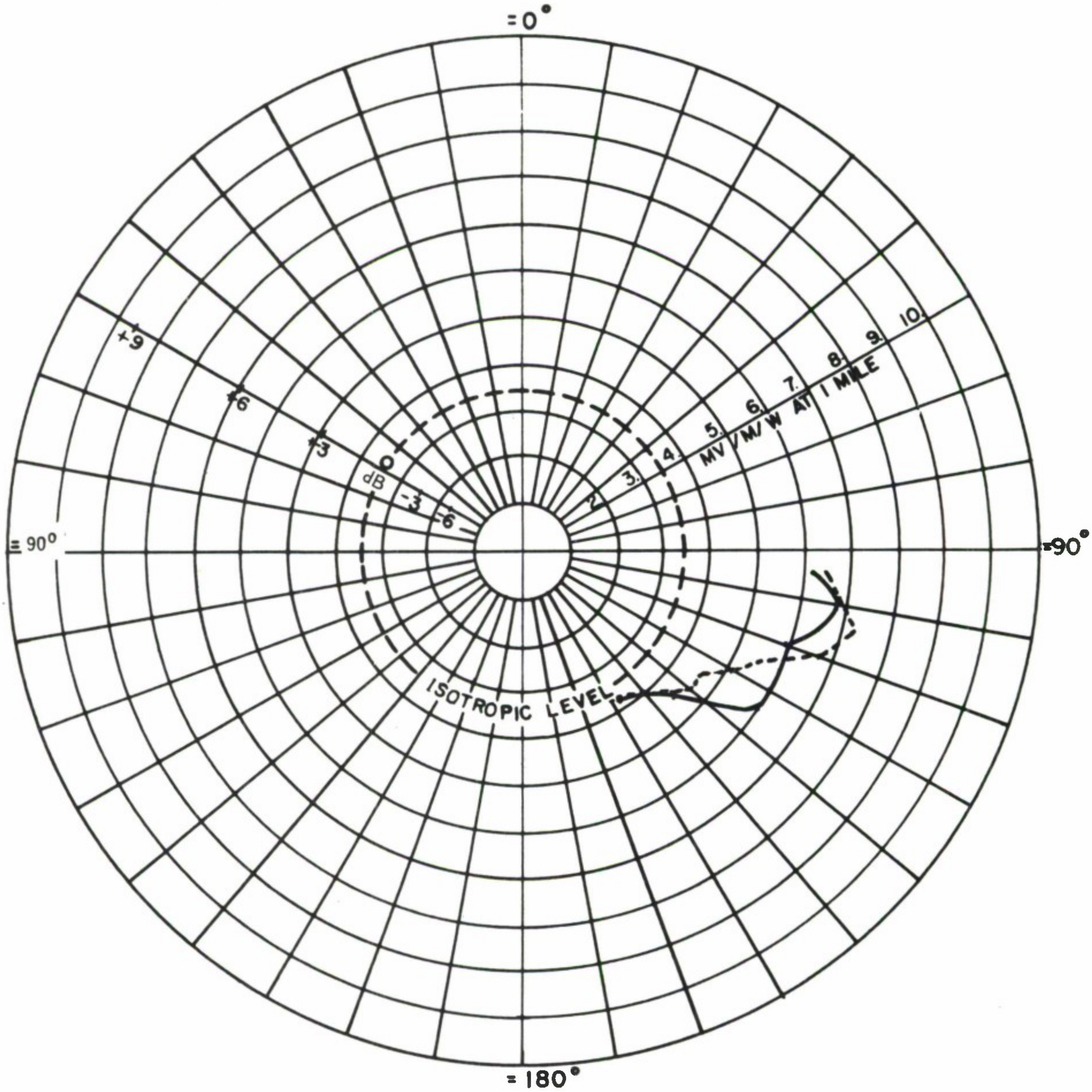


FIGURE 89. VHF SIGNAL LEVEL VS RANGE

SOLID LINE: INFLIGHT DATA (237.8 MHz)
DASHED LINE: MODEL STUDY(4.76 GCS)
FIELDS PLOTTED IN VOLTAGE



AZIMUTH (ϕ): 000° ± 2°
ELEVATION (θ): VARIABLE

AT 840/ARC VHF BLADE LOCATED AT BOTTOM FUSELAGE STATION S70

FIGURE 90. VHF VERTICAL PLANE RADIATION PATTERN

Goal

Determine the VHF data dump antenna radiation pattern so that optimum flight patterns for data dump can be formulated.

Conditions

With the A/RIA at 35,000 feet, the circular pattern shown in Figure 85 as Flight Plan 2 was flown. The data dumped were a 51.2-KBPS bit stream at the Apollo format recorded on a 450-KHz FM subcarrier deviated $\pm$ 30 percent. The prerecorded tape was furnished by ETR to Douglas requirements. The VHF carrier frequency was 237.8 MHz.

Test Results

The P-Band (237.8 MHz) horizontal plane radiation pattern is shown in Figure 91. The solid line represents the data obtained during the segmented circle flight pattern. The dashed line connects specific points taken from the 1/20 scale model study (converted to MV/M/W at 1 mile) with an elevation angle of 90°. The close similarity of the two patterns indicates that no appreciable changes have been incurred since the study was undertaken and that the model studies may be used for operational planning. These studies are presented in Report No. DAC 56126.

The major radiation perturbations are evident in both polar graphs, particularly in the wing and engine area. Although the major portions of the patterns show the gain of the VHF antenna to be above that of an isotropic radiator, some loss of gain is to be expected where aircraft structure has a disturbing effect. This loss can be compounded by a wing-down condition during a transmission period.

The conical warp of the in-flight pattern is slight. The airplane was less than 1 degree above the horizon, and the sinusoidal variation in the elevation angle was limited to the 3.5-degree nose-up, tail-down flight attitude.

It is evident from these two patterns that the forward radiation hemisphere presents the smoothest gain levels and should be used whenever possible.

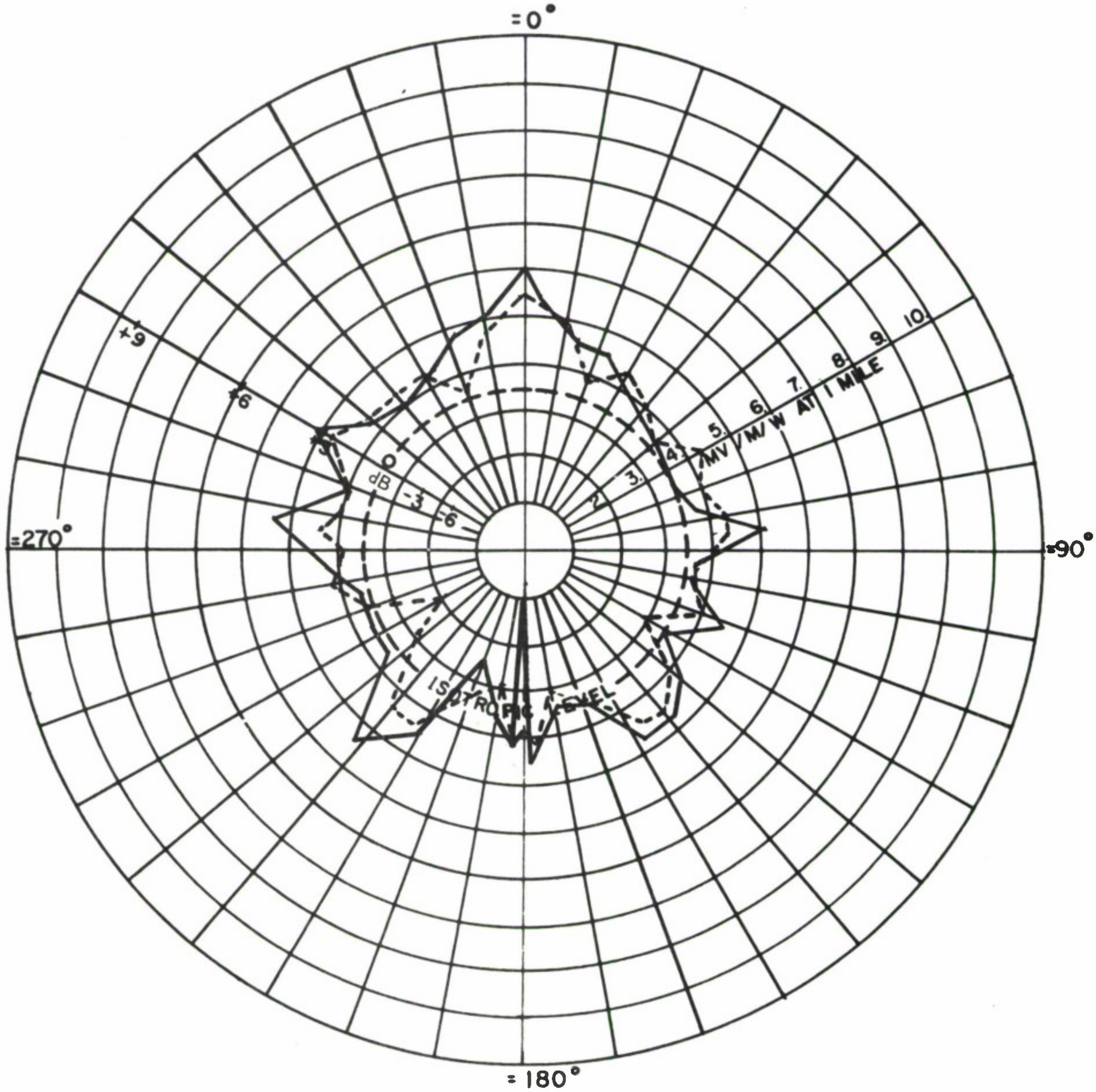
3.9.5.4 System Performance —— Test 4

Dump prerecorded Apollo format 51.2 KBPS data to TEL IV-ETR at UHF to determine data dump range.

Goal

The goal of this test is to determine the maximum range at which A/RIA could dump useful data at UHF.

SOLID LINE: INFLIGHT DATA (237.8 MHz)
DASHED LINE: MODEL STUDY(4.76 GCS)
FIELDS PLOTTED IN VOLTAGE



AZIMUTH (ϕ): VARIABLE
ELEVATION (θ): 86.5° AT NOSE

AT 840/ARC VHF BLADE LOCATED AT BOTTOM FUSELAGE STATION 570

FIGURE 91. VHF HORIZONTAL PLANE RADIATION PATTERN

Conditions

The A/RIA flew an inbound radial to TEL IV as shown in Figure 84, Flight Plan 1. The data dumped were a 51.2-KBPS bit stream at the Apollo format recorded on a 450-KHz FM subcarrier deviated $\pm$ 30 percent. The transmitter was operated PCM/FM at a carrier frequency of 2287.5 MHz. The UHF transmitter power was set to 0.5 watt for these tests. The cable loss from the transmitter to the antenna was measured just prior to the test.

Test Results

The test was successfully performed on Flight 28 simultaneously with the VHF tests. Figure 92 is a plot of the received signal level in the left hand circular (LHC) channel at TEL IV. (The RHC channel malfunctioned and the data could not be used.) An isotropic radiator level is also presented on this plot for reference. An examination of the TEL IV recordings indicated that the S-Band tracking was very poor with an excessive scan envelope. The records also indicate that the majority, if not all, of auto-track was conducted in the VHF mode. Since the VHF tracking beam width was approximately 19 degrees at the half-power points and the UHF was approximately 1.9 degrees, the roll-off of UHF was rapid and almost impossible to compensate. (It is also suspected that the TEL IV VHF and UHF boresights are significantly different.)

A combination of tracking error, tracking antenna elevation limits, and propagational characteristics caused the large variations shown in Figure 92. Superimposed on the plot is the theoretical scan envelope maxima and minima based on the following characteristics:

a. 4/3rds earth propagation

b. TEL IV receiving antenna 32 feet above land and 42 feet above water

c. Atmospheric absorption of 0 dB

d. Scan loss of 1 dB

e. 0-degree azimuth error

f. Transmitting antenna gain of 5 dB.

Although it is obvious that the propagational characteristics were not those of the ideal 4/3rds earth, the deviation of the signal levels from the depicted envelope and inspection of the data reveal excessive tracking error. Datum inspection also reveals that sync drop-out was occurring coincidentally with the receiving antenna scan rate at ranges greater than approximately 130-nm. On this basis, it is invalid to use a bit-error count to determine the maximum range of the UHF data dump system. Rather, the peak signal levels indicate that the system is theoretically capable of operation to near the radio horizon, and the restraints placed upon it are those of the receiving

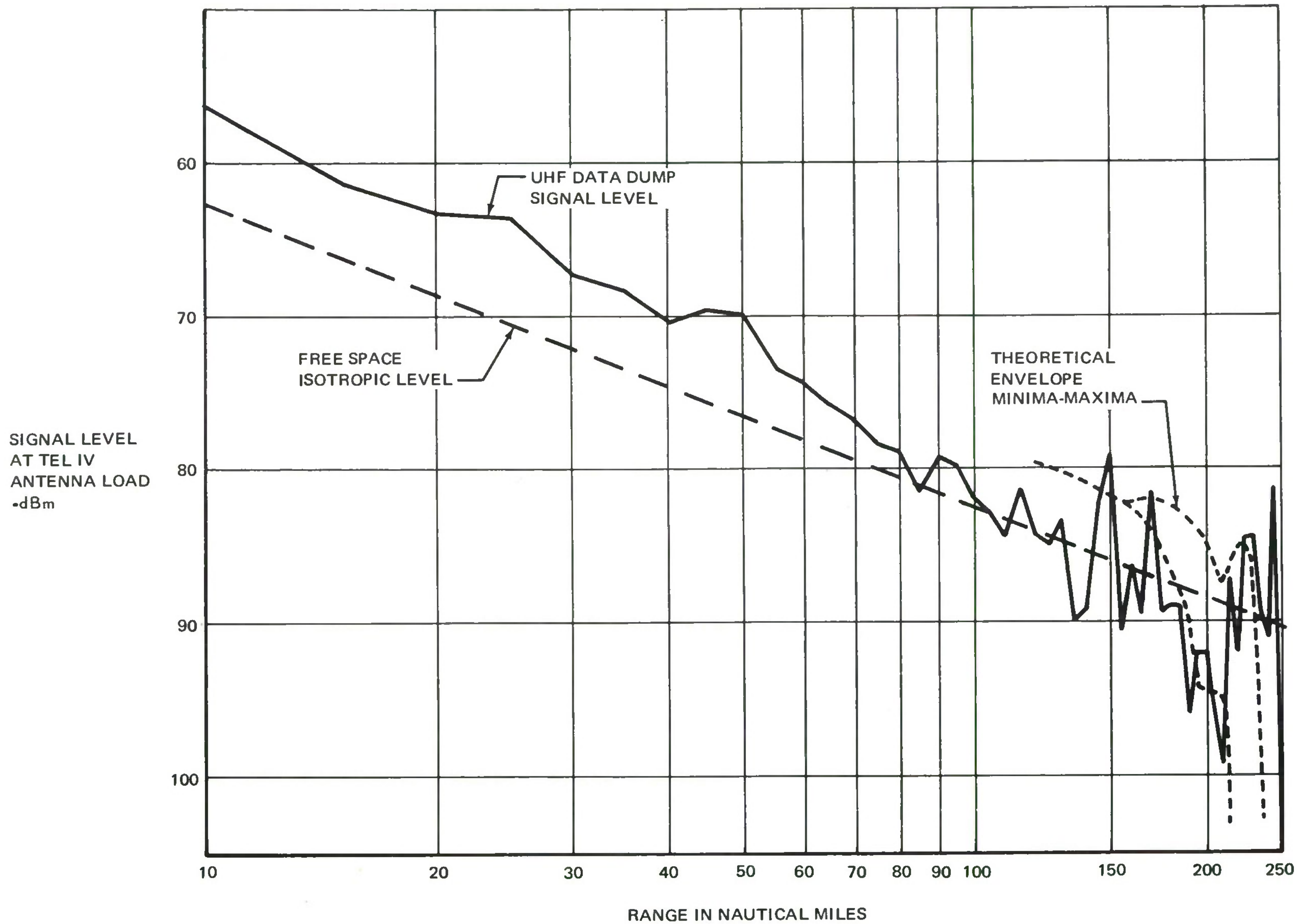


FIGURE 92. UHF SIGNAL LEVEL VS RANGE

station. (Correlation of this was that periods of good tracking resulted in error-free data.) The same operational procedure recommended for VHF data dump is also recommended for VHF.

3.9.5.5 System Performance —— Test 5

S-Band (UHF) data dump radiation pattern checks.

Goal

Determine the UHF data dump antenna radiation pattern so that optimum flight patterns for data dump can be formulated.

Conditions

With the A/RIA at 35,000 feet, the circular pattern shown in Figure 85 as Flight Plan 2 was flown. The data dumped were a 51.2-KBPS bit stream at the Apollo format recorded on a 450-KHz FM subcarrier deviated ± 30 percent. The prerecorded tape was furnished by ETR to Douglas requirements. The UHF transmitter was operated PCM/FM at a carrier frequency of 2287.5 MHz.

Test Results

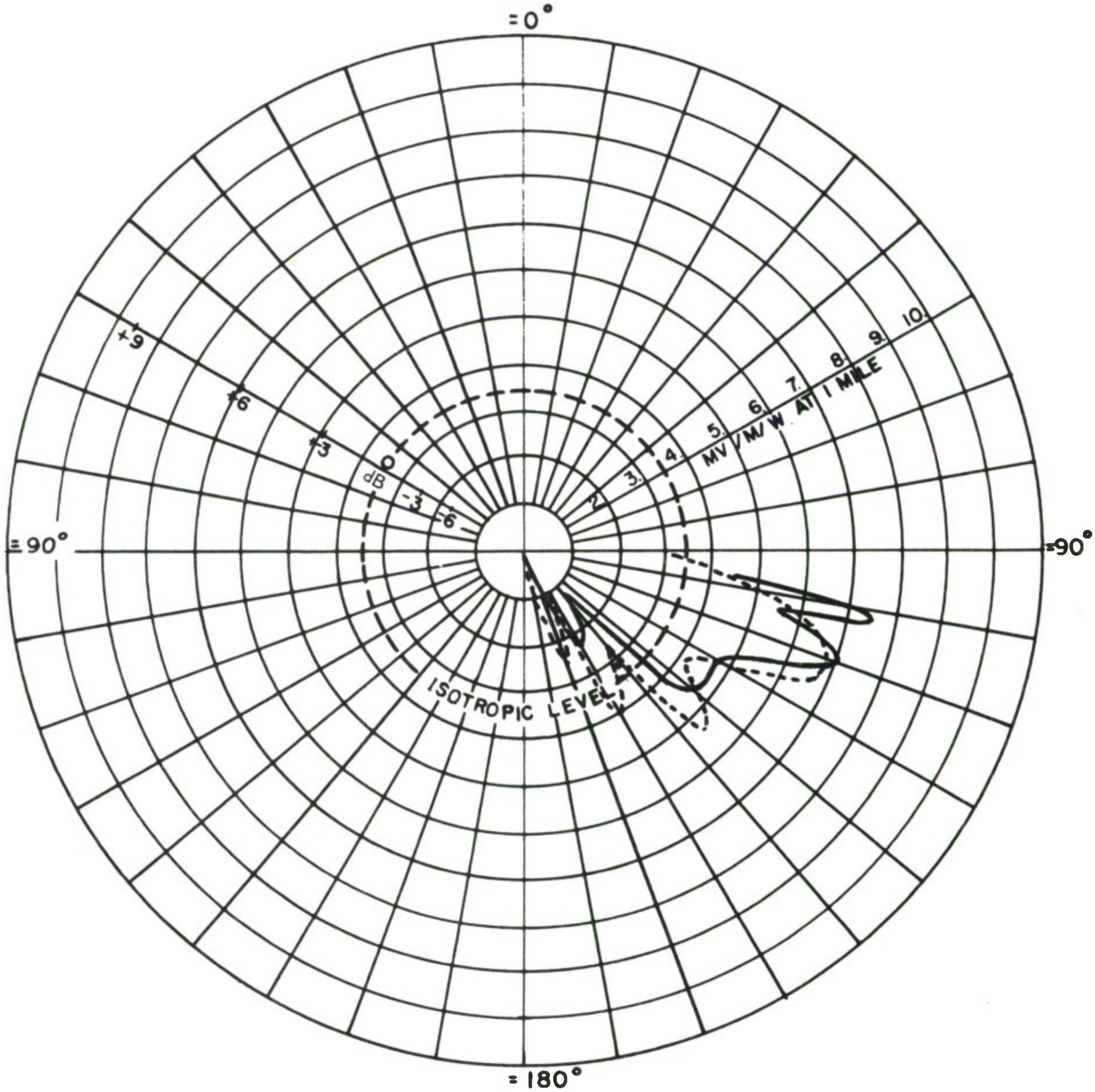
The S-Band horizontal and vertical plane radiation patterns are shown in Figures 93 and 94. In view of the test constraints discussed previously, the patterns can only be considered representative of the approximate pattern shape and values. The laboratory radiation studies were conducted at the full scale frequency of 2287.5 MHz with the antenna mounted on a flat ground plane. Since there was no representative aircraft structure included in the studies, the resultant horizontal pattern was omnidirectional. The gain could be and was used to correlate the gain off the nose of the aircraft and to reference the vertical cut.

A study of the in-flight radiation pattern indicates that wing shadowing and reflections from structure play an important part in the final pattern. The shadowing off the tail is assumed to be caused by the normal flight attitude of the A/RIA (3.5 to 4.5 degrees nose-up, tail-down) and the trailing wire nest and drogue. It is recommended that UHF data dumping be conducted at aspect angles forward of the 090 to 270-degree points.

3.9.6 Functional Reliability/Operability

No failures occurred during data dump tests. The test results indicate that UHF and VHF equipment operated as designed.

SOLID LINE: INFLIGHT DATA (2287.5 MHz)
DASHED LINE: LAB DATA (2287.5 MHz)
FIELDS PLOTTED IN VOLTAGE

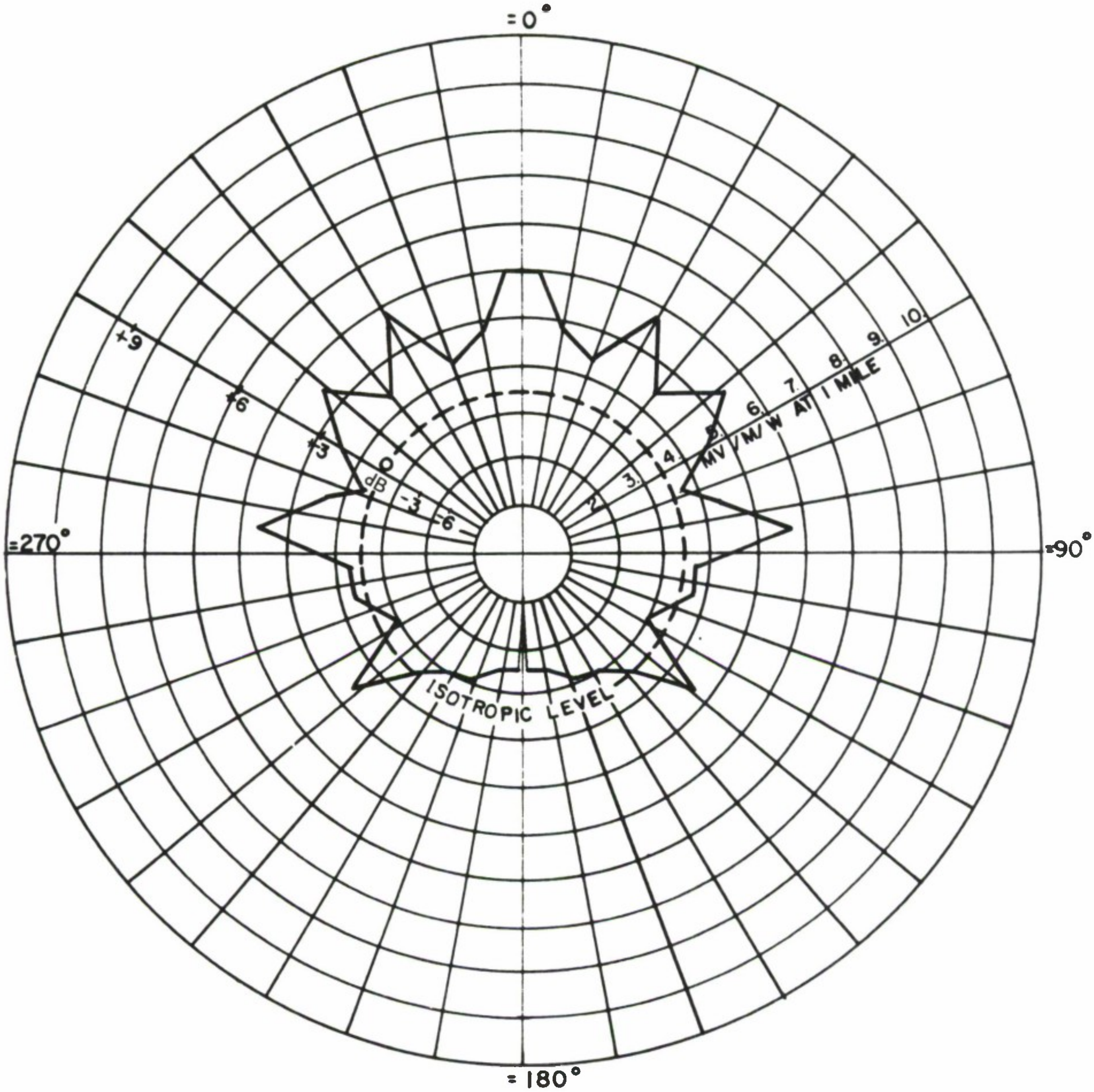


AZIMUTH (ϕ): 000° ± 2°
ELEVATION (θ): VARIABLE

CA-253 ANNULAR SLOT AT BOTTOM FUSELAGE STATION 610.3
(THESE PATTERNS ARE REPRESENTATIVE, NOT ABSOLUTE)

FIGURE 93. UHF VERTICAL PLANE RADIATION PATTERNS

SOLID LINE: INFLIGHT DATA (2287.5 MHz)
FIELD PLOTTED IN VOLTAGE



AZIMUTH (ϕ): VARIABLE
ELEVATION (θ): 86.5° AT NOSE

CA-253 ANNULAR SLOT AT BOTTOM FUSELAGE STATION 610.3
(THESE PATTERNS ARE REPRESENTATIVE, NOT ABSOLUTE)

FIGURE 94. UHF HORIZONTAL PLANE RADIATION PATTERNS

3.9.7 Design/Operational Problems

3.9.7.1 Data Dump of the Unified S-Band 1.024 MHz Subcarrier

Several ground tests proved that upon playback of the recorded subcarriers, the USB data demodulators would not lockup on the pulse trains. A technical explanation follows:

The signal data demod cannot demodulate the USB data from the M-28 wideband recorder. It appears the problem is due to the flutter, time displacement error, and steady state timing error of the wideband recorder.

It appears that there are three potential problem areas. The low frequency flutter components that are within the 150-cycle bandwidth of the signal data demod phase lock loop may be generating considerable random phase noise that cannot be distinguished from the data. The high frequency flutter components that are outside this 150-cycle bandwidth are creating phase errors that the signal data demod cannot track. The steady rate frequency error can easily be outside the frequency range that the signal data demod can accept. The steady state error of the recorder is specified at 0.2 percent or approximately 2 KHz, and this is well outside the limit of the signal data demodulator.

It does not appear that there is anything that can be done internally to the M-28 recorder to overcome this problem. The cumulative peak-to-peak flutter of this recorder is 0.25 percent, which is typical of present-day instrumentation recorders. A low mass capstan recorder with low time displacement error could alleviate the situation by reducing the effect of the low frequency flutter components, but it is not known if this would be sufficient to correct the problem.

It appears at this time that the only possible solution is to generate an error signal from the recorder and use this as a forcing function in the demodulator phase lock loop.

It is recommended that the telemetry data received from Apollo by Unified S-Band be recorded at baseband and dumped in the PCM/FM mode.

3.10 TIMING SYSTEM

Test Result Summary

The results of the tests of the timing system met the desired goals. In-flight synchronization with universal time (UT-2) on four successive flights showed an average drift of 0.49 milliseconds. Time coincidence of identical timing signals between redundant time signal generators was maintained throughout the tests. The average drift of the secondary standard was 2.39 microseconds in a 10-minute period (accuracy 3.65 X 10^{-9}). There were no in-flight failures of the timing system or timing signals that compromised test results.

3.10.1 Tests Performed

Test 1 Maintain synchronization with universal time within 2.0 milliseconds while in flight. (Reference Category II Flight Test Procedure, Paragraph 7.13.C.1)

Test 2 Maintain time coincidence of identical timing signals from the redundant time signal generators while in flight. (Reference Category II Flight Test Procedure, Paragraph 7.13.C.2)

Test 3 Check that the secondary time standard will maintain an accuracy of 1×10^{-8} while in flight. (Reference Category II Flight Test Procedure, Paragraph 7.13.C.3)

3.10.2 Test Environment

All timing tests were made in a single environment, tining system in-flight with synchronization signals from WWV.

3.10.3 Test Data Collection Techniques

All timing measurements were made by the PMEE Timing-Record Operator. Timing signals were continuously recorded on the two CEC oscillographs (IRIG "E") and the brush event recorder (IRIG "C"). GMT time readout was recorded on the photo recorder.

3.10.4 System Configuration

Timing system configuration for timing system Tests 1 and 2 is shown in Figure 95. Configuration for timing system Test 3 is shown in Figure 96.

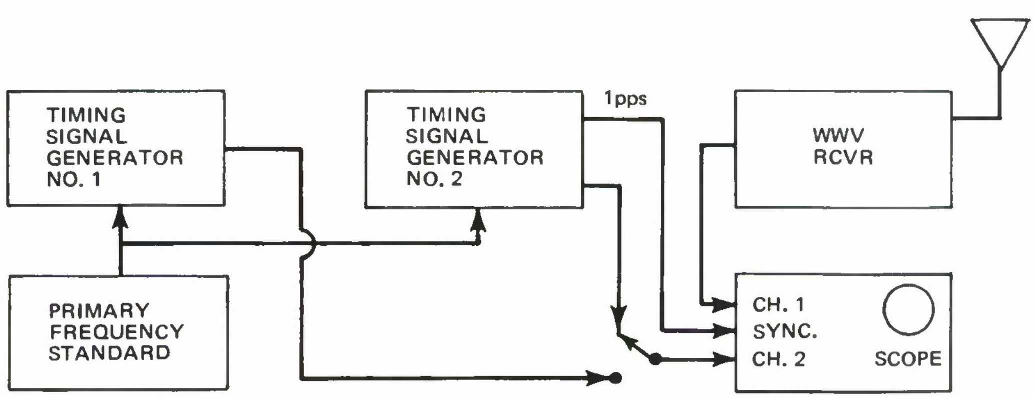


FIGURE 95. TIME SIGNAL GENERATOR TEST CONFIGURATION

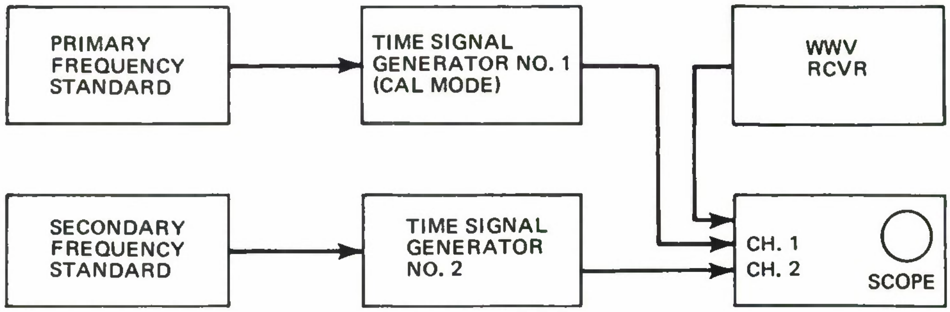


FIGURE 96. FREQUENCY STANDARD TEST CONFIGURATION

3.10.5 System Performance

3.10.5.1 System Performance —— Test 1

Verify that time synchronization to universal time (UT-2) can be maintained while in flight to an accuracy required to support Apollo missions.

Goal

Maintain time sync to less than 2.0 milliseconds, which is the possible error due to propagation variations.

Conditions

The timing system was synchronized with WWV prior to flight. After the flight, a time check was made to determine the accumulated time error. The WWV signal propagation delay was taken as 4.2 milliseconds for the Tulsa area.

Test Results

The results of the UT-2 synchronization tests were satisfactory, as shown in Table L. The accumulated error on each of the four flights was within the goal.

3.10.5.2 System Performance —— Test 2

Verify that time-coincidence of the redundant time signal generators can be maintained in a flight environment.

Goal

The automatic monitoring circuits of the signal monitor and switching panel do not detect a non-coincidence condition during flight.

TABLE L

Time Signal Generator Accumulated Drift

Flight Number	Accumulated Error	
	Goal	Measured Result
16	2.0 millisec	0.26 millisec
18	2.0 millisec	0.32 millisec
19	2.0 millisec	1.3 millisec
20	2.0 millisec	0.1 millisec
Average, 4 Flights	2.0 millisec	0.49 millisec

Conditions

TSG-1 and TSG-2 were synchronized to within 0.5 microseconds prior to flight. The fault alarm indicators were monitored during flight. The 1 PPS alarm responds to any non-coincidence condition exceeding 1 microsecond, and the timing code alarm responds to non-coincidence exceeding 10 microseconds.

Test Results

No fault indications appeared during the timing system tests. The results of the TSG-1 and TSG-2 time coincidence tests were satisfactory.

3.10.5.3 System Performance —— Test 3

Evaluate the effect of flight environment on the accuracies of the prime and secondary standards.

Goal

Drift of less than 6 microseconds (accuracy 1 X 10^{-8}) between the primary and secondary frequency standards over a 10-minute period.

Conditions

With the configuration shown in Figure 96, TSG-1 and TSG-2 were synchronized prior to flight. The drift over a 10-minute period was measured at 30-minute intervals throughout the flight.

Test Results

The results of the tests run during Flight 16 met the goal of an allowable drift of 6.0 microseconds. The test was rerun on Flight 18 to establish repeatability of data. Eleven measurement periods yielded a maximum drift of 4.4 microseconds (7.3 X 10^{-9} accuracy) and an average drift of 2.6 microseconds (4.3 X 10^{-9} accuracy) (Reference Table LI).

TABLE LI

Primary Versus Secondary Standard Accumulated Drift

PERIOD #	ALLOWABLE DRIFT (μ Sec)	MEASURED DRIFT (μ Sec)	ACCURACY
1	6.0	0.8	1.3 X 10^{-9}
2	6.0	0.1	1.6 X 10^{-10}
3	6.0	0.85	1.41 X 10^{-9}
4	6.0	1.8	3.0 X 10^{-9}
5	6.0	2.5	4.16 X 10^{-9}
6	6.0	2.7	4.5 X 10^{-9}
7	6.0	3.0	5.0 X 10^{-9}
8	6.0	3.2	5.3 X 10^{-9}
9	6.0	3.7	6.16 X 10^{-9}
10	6.0	3.2	5.6 X 10^{-9}
AVERAGE	6.0	2.18	

3.10.6 Functional Reliability/Operability

No malfunctions, synchronization faults, or loss of timing signals occurred during flight tests of the timing system.

3.11 INTEGRATED SYSTEM TESTS

Nonavailability of Apollo spacecraft prevented complete evaluation of the A/RIA performance in the specified Modes I and II operation. For this reason, available space

missions (Gemini XII and ballistic missiles) were used for system evaluation and the data extrapolated to the design performance of the Apollo System to the performance of the A/RIA in terms of expected Apollo performance. Acquisition and tracking on UHF was stable and accurate with the UHF error voltage indicating less than $\pm 2^{\circ}$ of error. UHF telemetry data SNR averaged 8.5 dB on UHF/LHC. Five VHF telemetry links averaged 20 dB SNR. Uplink and downlink voice relays were accomplished and evaluated as 5/4 and 4/4, respectively. Teletype messages were transmitted and received, using quad tone diversity with doppler correction, with an average of 2.85 errors per line over 100 lines. Time signal generators 1 and 2 were synchronized to WWV before flight; post flight checks revealed that synchronization was maintained within 0.1 microsecond. One VHF telemetry receiver failed during the tests.

3.11.1 Tests Performed

Test 1 Perform functions described as Mode I in SS 100000 simultaneously.

Test 2 Perform functions described as Mode II in SS 100000 simultaneously.

Specifications

System will operated in Apollo Mode I and Mode II configuration in accordance with flight test requirements as specified in SS 100000, Paragraph 4.2.1.1.2.2.

Goal

No degradation of any function when all functions operate simultaneously.

3.11.2 Test Environment/Conditions

These tests were performed in the standard racetrack pattern, using the Tulsa ground station and a second A/RIA on the ground. The Tulsa ground station transmitted VHF and USB data at predicted Apollo levels and provided the VHF voice link for voice relay tests. The ground-based A/RIA transmitted and received HF voice and teletype. (See Figure 97)

Test conditions are those specified in SS 100000. These included:

a. Acquisition and tracking in UHF optimum, using a Unified S-Band format with a 1000-Hz tracking phase-lock-loop, at a received signal power of 2.3×10^{-14} watts/m^2. (Power level ref: CP 100002) (Frequency: 2287.5 MHz)

b. Receiving and recording Unified S-Band data, 51.2 KBPS, at 2.3×10^{-14} watts/m^2.

c. Receiving and recording Unified S-Band voice, using a prerecorded voice message, at 2.3×10^{-14} watts/m^2.

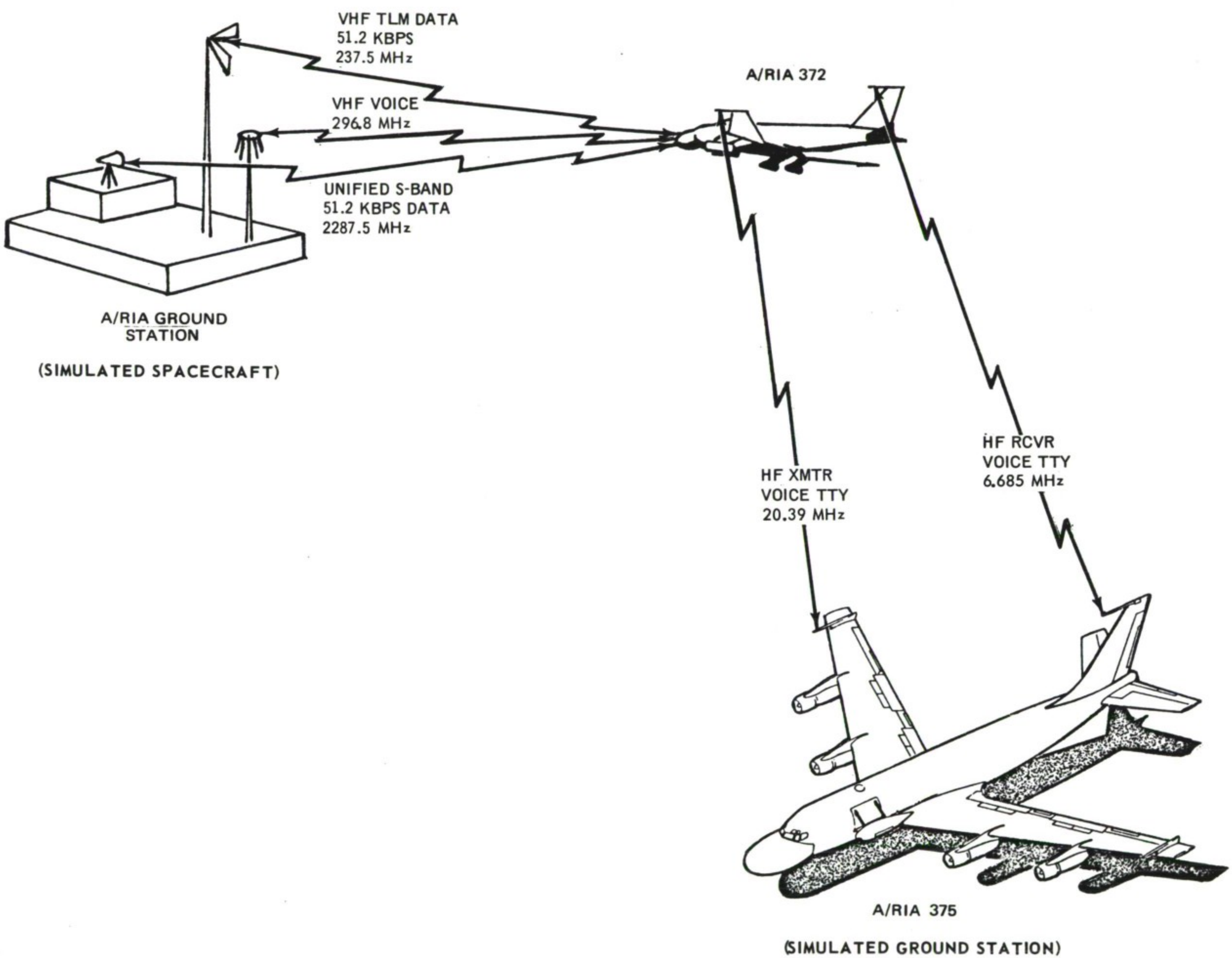


FIGURE 97. TEST ENVIRONMENT

d. Receiving and recording VHF PCM/FM telemetry data, 51.2 KBPS, at 237.8 MHz at 1.1×10^{-14} watts/m^2 on six telemetry receivers simultaneously. (Power level reference CP100002A).

e. Receiving and recording VHF voice, using a prerecorded voice message, at 296.8 MHz at 1.8×10^{-14} watts/m^2 (power level reference CP100002A).

f. Relay VHF combined voice downlink by HF (Mode I) and relay HF voice uplink by VHF (Mode II).

g. Receive and transmit HF voice (transmit prerecorded voice message).

h. Transmit teletype at 100 words per minute during the voice relay.

i. Receive and record VHF and USB verification voice.

j. Maintain time sync with WWV.

3.11.3 Data Collection Techniques

Sources of data for these tests were completed flight cards, operators' logs, oscillograph, and event recorder records, audio and wideband magnetic tapes, flight debriefings, ground station logs, teletype messages, and interviews with the A/RIA operators. The receiver signal strengths were recorded on both the WB recorder and the oscillographs. A comparison was made of the reduced AGC data.

3.11.4 System Configuration

The A/RIA PMEE configuration for these tests is shown in the Integrated System Block Diagram, Figure 98. This configuration is in accordance with that specified in Apollo Modes I and II operational concepts, with the exception of a second UHF data link. It was not possible to transmit a Unified S-Band and UHF PCM/FM link simultaneously from the A/RIA ground station. Also, uplink voice relay by UHF was not possible because the ground station could not demodulate the UHF voice subcarrier. The seventh (spare) telemetry receiver is not shown in the diagram, since it was specially patched to serve as a VHF voice receiver during a squelch modification test also performed on the flight.

As shown on the diagram, the A/RIA was configured to acquire and track on UHF (Unified S-Band), with the VHF tracking receivers serving as back-up. The UHF track receivers were patched to receive USB data, while the six VHF telemetry receivers were set to receive PCM/FM data. The spacecraft voice links were configured to receive and transmit VHF and USB voice, while the HF subsystem was patched to receive and transmit voice and teletype. The system was patched for voice relay. The timing subsystem was synchronized to WWV. The wideband and audio recorders were patched as follows:

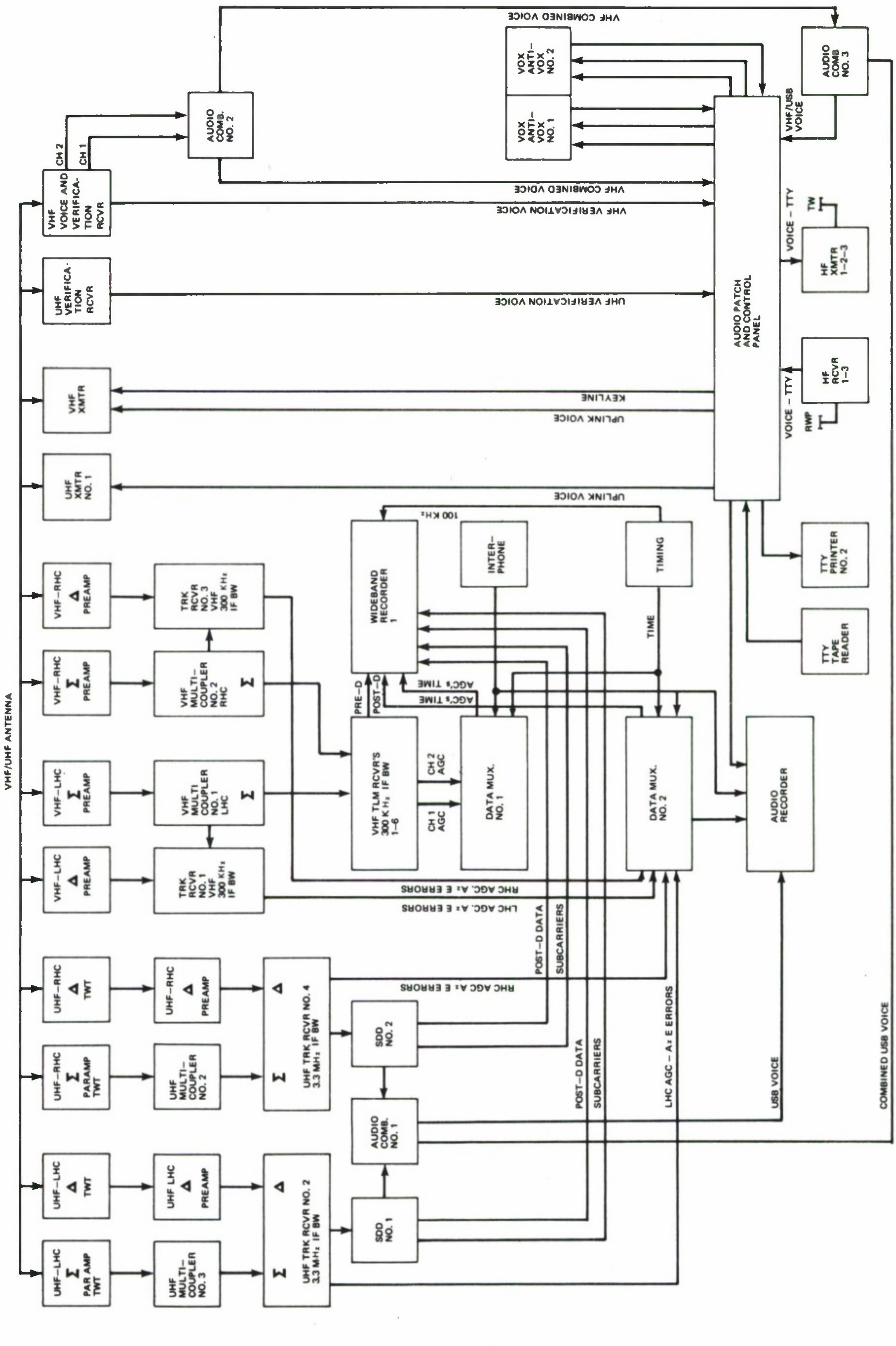


FIGURE 98. INTEGRATED SYSTEM BLOCK DIAGRAM

WB Recorder Patching

Ch. 1 - VHF TLM RCVR 1 PRE-D COMB, 800 KHz

Ch. 2 - VHF TLM RCVR 2 PRE-D COMB, 800 KHz

Ch. 3 - VHF TLM RCVR 3 PRE-D COMB, 800 KHz

Ch. 4 - VHF TLM RCVR 4 PRE-D COMB, 800 KHz

Ch. 5 - VHF TLM RCVR 5 PRE-D COMB, 800 KHz

Ch. 6 - VHF TLM RCVR 6 PRE-D COMB, 800 KHz

Ch. 7 - SDD-2 Wideband Video (USB subcarriers)

Ch. 8 - SDD-1 Wideband Video (USB subcarriers)

Ch. 9 - Data Mux 1, Output 1

Ch. 10 - Data Mux 2, Output 2

Ch. 12 - 100 KC reference from timing

Ch. 13 - SDD 2, 51.2 KBPS data, TRK RCVR 4 (USB)

Ch. 14 - SDD 1, 51.2 KBPS data, TRK RCVR 2 (USB)

Audio Recorder Patching

Ch. 1 - Timing (Data Mux 2, Output 2)

Ch. 2 - VHF COMBINED VOICE (Combiner 1)

Ch. 3 - USB COMBINED VOICE (Combiner 2)

Ch. 4 - VHF/USB COMBINED VOICE (Combiner 3)

Ch. 5 - HF VOICE (HF RCVR)

Ch. 6 - VHF Verification Voice (Verification Receiver)

Ch. 7 - Voice Annotation (Interphone)

3.11.5 System Performance

3.11.5.1 UHF Tracking

A/RIA acquired and tracked on UHF/LHC at a measured signal level of 2.3×10^{-14} watts/m^2 (-105.5 at the A/RIA directional coupler). Tracking was very stable, as evidenced by solid AUTO TRACK throughout the data run. Measurement of UHF error signals indicated that tracking accuracy was $\pm 2^{\circ}$ throughout the run.

3.11.5.2 UHF Telemetry Data (See Table LII)

The SNR of the 51.2-KBPS Unified S-Band data from the UHF/LHC channel measured 8.5 dB at the beginning of the run and 9.5 dB at the end of the run. These values compare to computed output SNR's of 8.8 dB and 9.8 dB at the received power levels of -105.5 dBm and -104.5 dBm, respectively. The UHF/RHC channel was not operating properly during the run, even though the AGC calibration indicates that the channel was receiving a signal comparable to that seen on LHC. The malfunction was later isolated to low gain from the RHC parametric amplifier.

The measured signal power on this run agrees with the level computed by analysis. The signal level increased from the beginning of the run to the end, as predicted by the radiation pattern check preceding the run.

3.11.5.3 VHF Telemetry Data (See Table LII)

The SNR's from five telemetry receivers measured 21 dB (average) at the beginning of the run and 18.5 dB (average) at the end of the run. Although the AGC shows an increase in signal plus noise from the beginning to the end of the run, the measured SNR's decreased an average of 2.5 dB. This decrease is the result of increased man-made noise as the aircraft neared the Tulsa area. This noise increase was predicted and was measured on another Category II flight as approximately 4 dB. This noise level is comparable to that measured over other American cities as outlined in a report from Lincoln Labs (see Signal Control and Calibration, Section 3.1.5).

The measured SNR of the 51.2-KBPS PCM/FM data compares with the computed values on the five VHF telemetry links used during this test. When comparing measured to computed SNR's, the following tolerance applies:

$$SNR_c = SNR_m + \Delta N \pm E_m$$

$$SNR_c = SNR_m + 4dB \pm 2dB$$

where:

SNR_c = Computed signal-to-noise ratio

SNR_m = Measured signal plus noise to noise

ΔN = The increase of noise over zenith

E_m = Measurement error of received signal power

TABLE LII

UHF/VHF Telemetry SNR, Integrated System Test

Signal	Receiver #	Record Mode	Recorder Track	Measured Signal (-dbm) Power at Directional Coupler				Measured S+N/N (db)		Computed SNR (db)** NOTES #1, #2	
				Start of Run		End of Run		Start of Run	End of Run	Start of Run	End of Run
				CH #1	CH #2	CH #1	CH #2				
VHF, PCM/FM 51.2 KBPS Pre-Detection Combined	Telemetry #1	Direct, fc= 800KC	1	102	100	97	98	21.0	20.0	20.1	23.1
VHF, PCM/FM 51.2 KBPS Pre-Detection Combined	Telemetry #2	Direct, fc= 800KC	2	100	101	95	97	23.0	19.0	20.1	25.1
VHF, PCM/FM 51.2 KBPS Pre-Detection Combined	Telemetry #3	Direct fc= 800KC	3	101	100	97	97	22.5	17.5	20.1	23.1
VHF, PCM/FM 51.2 KBPS Pre-Detection Combined	Telemetry #4	Direct fc= 800KC	4	100	100	96	97	23.0	19.0	20.1	24.1
VHF, PCM/FM 51.2 KBPS Pre-Detection Combined	Telemetry #5	Direct fc= 800KC	5	102	101	96	97	15.0	16.0	19.1	24.1
UHF, Unified S-Band 51.2 KBPS LHC Polarization	Track #2	FM fc= 900KC	13	105.5		104.5		8.5	9.5	8.8	9.8
UHF, Unified S-Band. 51.2 KBPS RHC polarization	Track #4	FM fc= 900KC	14	*		*		2.5	3.5	*	*

* See paragraph 3.11.6.

**These computed values are derived by considering the channel having the higher measured power. The measured S+N/N ratios are taken from pre-detection combined data.

Computed SNR's are shown in Table LII for each of the measured received signal levels on each of the VHF telemetry receivers. At the start of the run, where man-made noise is lower, the measured SNR is slightly higher than computed on four of the five receivers. At the end of the run the measured SNR is 3.1 to 6.1 dB lower than the computed because of the increased noise.

Prior to the data run, the power supply in the sixth VHF telemetry receiver failed. The normal spare telemetry receiver (7) could not be used because it was configured for use as a voice receiver for a squelch modification evaluation.

3.11.5.4 Signal Strength Readouts

Figure 99 shows the signal strength plots from the five telemetry receivers as recorded by the oscillograph recorders, while Figure 100 shows the same signal strengths as recorded on the wideband recorder. The wideband recorder took the AGC's from the data multiplexer.

The deflection sensitivity on the oscillographs were set so that for most of the receivers a 10-dB signal variation yielded at least 1 inch of deflection. The deflection sensitivity used for reduction of the multiplexed AGC's from the wideband recorder was approximately 1 inch for 40 dB of signal change. It is apparent that the signal levels obtained from the oscillograph are the most accurate; however, the signal levels plotted from both sources are within 2 dB of each other. This agreement is as close as could be expected, considering the probability of accumulated readout error and possible inaccuracies accumulated during the MUX/Record process.

Comparison of the AGC's from the five receivers yields a maximum difference of 2 dB. This small difference may be attributed to accumulated equipment tolerance and readout error of AGC calibration. The GMT when SNR's were measured is annotated on the plots.

3.11.5.5 Voice Relay

This integrated system test was performed on Data Runs 1 and 2 on Flights 18 and 20. The downlink voice relay, VHF to ground by HF, was accomplished on Data Run 1 using a prerecorded tape message. The message was transmitted downlink from the ground station on USB and VHF simultaneously, but only the combined VHF was transmitted to ground on HF. Both VHF and USB voice signals at the Apollo levels were successfully recorded aboard the test aircraft. The messages were played back and evaluated by an experience voice communicator. Playback of the message recorded at A/RIA 375 was evaluated by an experienced voice communicator as 4/4.

The uplink voice relay, HF to the simulated spacecraft by VHF, was performed on Data Run 2 using a prerecorded voice message. Playback of the message recorded at the A/RIA ground station was evaluated by an experienced voice communicator as 5/4.

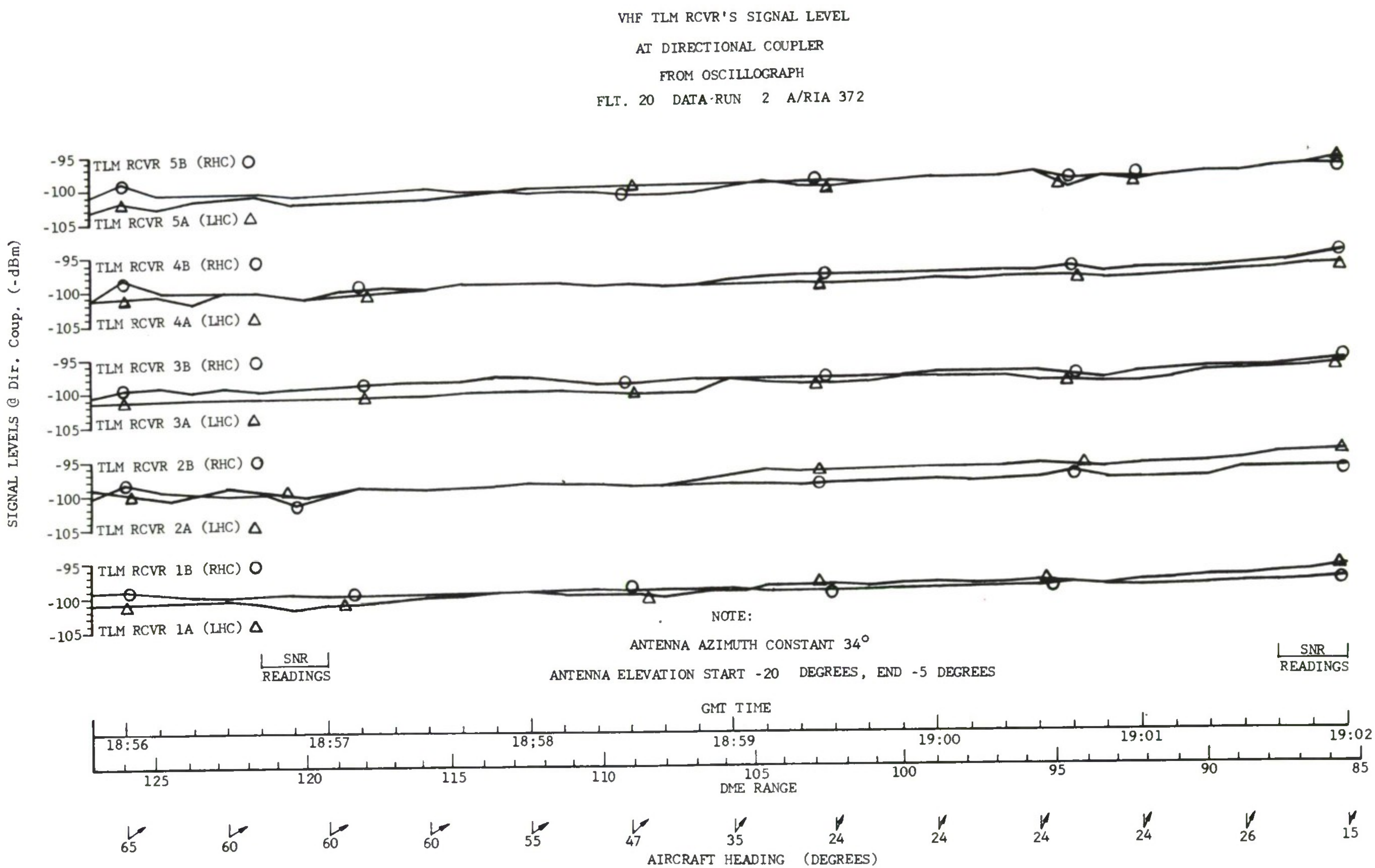


FIGURE 99. VHF TELEMETRY RECEIVER SIGNAL LEVEL PLOTS

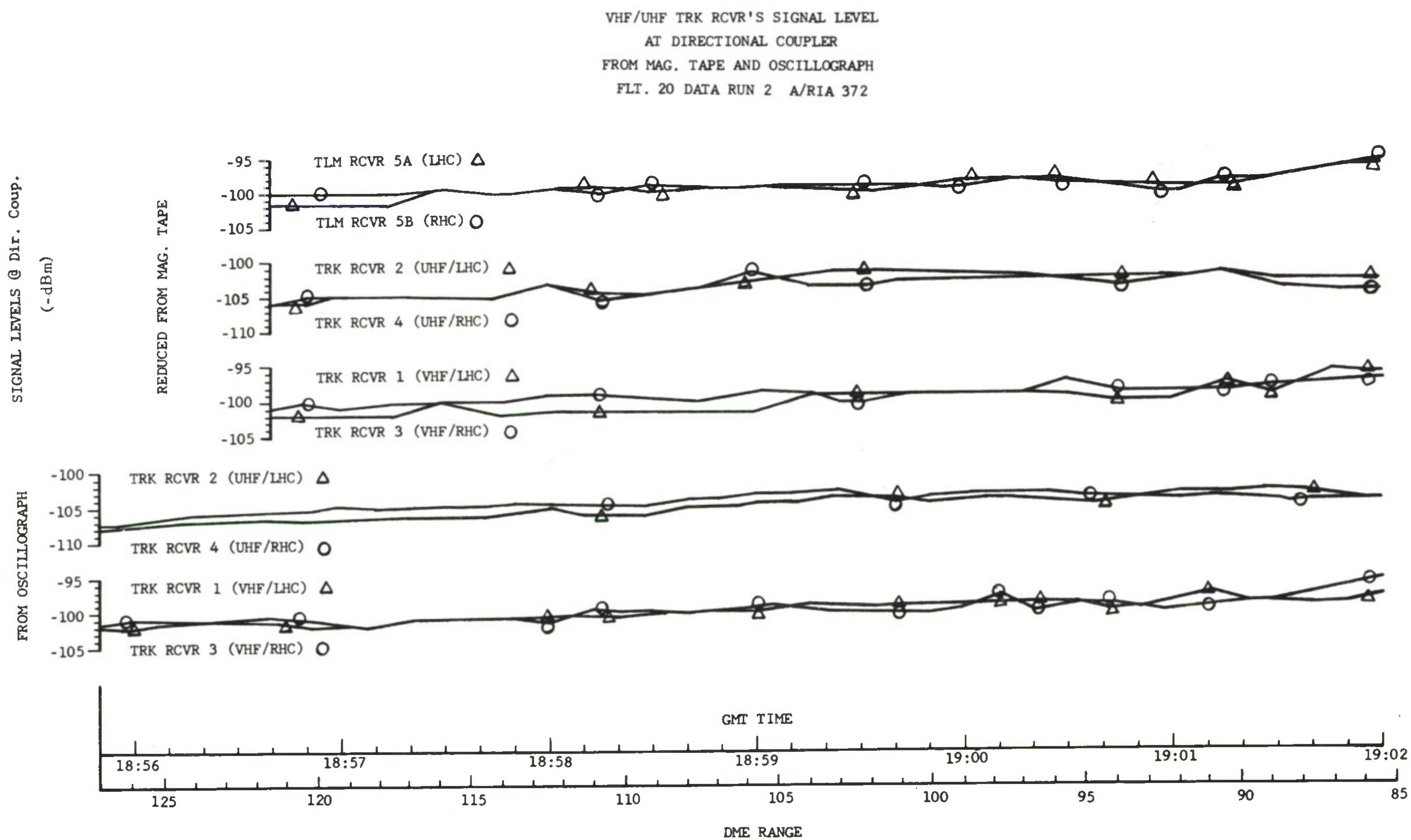


FIGURE 100. VHF/UHF TRACKING RECEIVER SIGNAL LEVEL PLOTS

3.11.5.6 Teletype

Teletype messages were transmitted and received at 100 words per minute (WPM), using independent side band (ISB) mode. Messages were sent between A/RIA 372 and A/RIA 375 (on the ground) during Data Run 2. The A/RIA's were configured as follows:

A/RIA 372

Transmit: Voice on sideband A1 (USB)

TTY on sideband B1 (LSB)

With 4-tone diversity

Frequency - 20.390 MHz

Power - 1 kw

Receive: Frequency - 6.685 MHz

Voice on sideband A1 (USB)

TTY on sideband B1 (LSB)

With 4-tone diversity

A/RIA 375

Transmit: Frequency 6.685 MHz

Voice on sideband A1 (USB)

TTY on sideband B1 (LSB)

With 4-tone diversity

Receive: Frequency 20.390 MHz

Voice on sideband A1 (USB)

TTY on sideband B1 (LSB)

With 4-tone diversity

Using four-tone diversity with doppler correction, an average of 2.85 errors per line was counted over 100 lines transmitted and received. This error rate is attributed to high noise on the HF link. A clear HF link during Tulsa operations was difficult to achieve owing to the few authorized HF frequencies available.

VHF voice communications were maintained with good intelligibility. The VHF and USB verification voice played back from the audio recorder was evaluated as intelligible by an experienced voice communicator.

Timing system signal generators 1 and 2 were synchronized to WWV with a time difference of 0.1 microsecond difference prior to engine start. Post flight check showed that synchronization to within 0.1 microsecond was maintained with WWV.

NOTE 1 Computation of VHF telemetry data SNR's

P_{dc} (Received signal power at directional coupler)	- 95 dBm
P_R (Received signal power at antenna load)	- 93 dBm
Φ (Noise Spectral Density)	-167.3 dBm/Hz
$(\frac{C}{N_1})$ dB = CNR in 1 HZ bandwidth	74.3 dB
Predetection Noise Bandwidth (300 KHz)*	54.8 dB
Predetection SNR	+ 19.5 dB

Evaluation of Output SNR

$(\frac{C}{N_1})$ dB	+ 74.3 dB
Post-detection noise bandwidth (10 log 2b). b = 125 KHz	54.0
FM Improvement: $10 \log \left[3(\frac{\Delta f}{b})^2\right]$	4.8 dB
Output SNR	25.1 dB

*IFBW = 2(Δ f + fm) = 2(125 + 37.5) = 325 KHz

Other Output SNR's applicable are:

P_{DC}	Pre-D SNR	Output SNR
- 96 dBm	18.5 dB	24.1 dB
- 97 dBm	17.5 dB	23.1 dB
- 98 dBm	16.5 dB	22.1 dB
- 99 dBm	15.5 dB	21.1 dB
-100 dBm	14.5 dB	20.1 dB
-101 dBm	13.5 dB	19.1 dB
-102 dBm	12.5 dB	18.1 dB

NOTE 2 Computation of Unified S-Band telemetry data SNR's

P_{DC} (Received signal power at directional coupler)	-105. 5 dBm
P_R (Received signal at antenna load)	-103. 6 dBm
Modulation loss (TM subcarrier)	4. 1 dB
Φ KT (Spectral Noise Density, $T_{SYS} = 1069^{o}K$)	-168. 3 dBm/Hz
$(\frac{S}{N_1})$ dB = SNR in 1 Hz bandwidth	60. 6 dB
Subcarrier predetection bandwidth (-10 log 150, 000)	51. 8 dB
Subcarrier predetection SNR	+ 8. 8 dB
Post detection bandwidth (-10 log 2 X 75, 000)	- 51. 8 dB
Output SNR	+ 8. 8 dB

The output SNR for P_{DC} = 104. 5 dBm is + 9. 8 dB.

3. 11. 6 Functional Reliability/Operability

The integrated system tests to SS 100000, Mode I and Mode II, were performed on Flights 18 and 20. During Flight 18, high man-made noise on VHF prevented successful completion of the tests. During Flight 20, the following conditions/equipment malfunctions compromised test results:

a. One VHF telemetry receiver failed after take-off, but prior to the data run. The cause of failure was the receiver power supply.

b. UHF/RHC Unified S-Band data had low SNR. This problem was found to be the result of two equipment deficiencies making the preflight and calibration results seem correct. The UHF RHC directional coupler attenuated port measured -12 dB instead of -31 dB, while the RHC parametric amplifier gain was down approximately 19 dB. The calibration did not reveal the problem since the AGC zero and -80 dB settings were based upon the 19-dB high input signal.

c. Very high VHF man-made noise required the VHF signal radiated from the ground station to be raised by 10 dB. This problem was common over Tulsa.

d. A noisy HF link made voice relays and teletype results less than optimum. This problem was caused by lack of adequate HF frequencies assigned to A/RIA at Tulsa.

Operation of A/RIA as an integrated system was accomplished to some degree on all Category II flights. Acquisition, tracking, reception, and recording of UHF and VHF telemetry data, VHF voice communications, and HF voice communications were established and maintained simultaneously on all flights. During Flights 6, 18, 19, and 20, voice relay and teletype were integrated with functions mentioned above. On Flights 23 and 27, seven VHF telemetry receivers successfully received data, primarily FM/FM, IRIG subcarriers 5 through 18. HF voice and teletype communications were established on these two flights. The operation of any function did not preclude the operation of any other function, and no inter-system RFI was detected.

3.11.7 Design/Operational Problems

It was difficult at Tulsa to set up adequate ground facilities to test the A/RIA as an integrated system as outlined in SS 100000. These tests required a ground station and a second A/RIA on the ground. The man-made noise at VHF frequencies over Tulsa degraded SNR's, and the limited available HF frequencies made error-free teletype and 5/5 HF voice links difficult to accomplish. It is assumed that when A/RIA is operating in its design environment, i.e., Apollo, the VHF noise level will be much lower and an adequate number of HF frequencies will provide a quieter HF link.

3.12 OPERATIONAL EVALUATIONS

The probability of mission completion is the most satisfactory measure of effectiveness of the A/RIA system. In addition to the many controlled test flights during Category II, the A/RIA participated in engineering tests with Gemini XII (GT-12) and a DOD ballistic missile. All major test objectives were met during these missions.

Participation in the Gemini XII mission took place on the 5th and 6th operational flights after PMEE instrumentation installation. The official NASA comment was stated "..... the performance of the A/RIA for this engineering test during GT-12 was satisfactory, particularly in light of the fact that instrumentation had been completely installed only two weeks prior to the mission. All NASA A/RIA test objectives were met ..... ". The A/RIA support was essentially qualitative in nature, but the information collected became extremely important because of following events. The slippage of Apollo left the Gemini mission as the only A/RIA spacecraft engineering test. The total analytical effort was somewhat compromised by lack of supporting information that was requested but not received by the Contractor. A discussion of the PMEE effort follows in Section 3.12.1.

The coverage of the ballistic missile occurred on the 20th engineering test flight of the Category II Program. This mission was officially designated as an "Award" mission under the performance award provision of the basic contract AF 19(628)-4888. In addition to being an award mission, this operation was considered to be a unique engineering test effort and the basic concept was directed toward this goal. The missile flight duration was nominalized to be 19-minutes, 20-seconds from lift-off to splashdown. Both the A/RIA flight path and the PMEE patching were designed to maximize

the quantitative data period. This mission was successful from an operational standpoint and the PMEE results are presented in Section 3.12.2.

The results of the above missions, combined with the results of normal Category II flight tests, are extrapolated to an Apollo mission in Section 3.12.3. This section, which is limited to PMEE configuration and operation, demonstrates the ability of the PMEE subsystem to meet the requirements of the Apollo mission. Section 3.13.4 discusses the operational aspects of the two missions regarding scheduling, availability, and control. Conclusions are reached in Section 3.12.5, and recommendations for specific flight path approaches for various types of mission coverage are made.

3.12.1 Gemini XII Coverage

3.12.1.1 Gemini XII Summary

A/RIA 372 was flown against Gemini XII on 12 November 1966 (Flight 8) and on 14 November 1966 (Flight 9). The objectives of these flights were to:

a. Acquire and track.

b. Qualitatively evaluate A/RIA while performing the following functions:

   (1) Receive and record VHF TLM data.

   (2) Establish uplink and downlink voice relay.

   (3) Establish HF duplex communications.

   (4) Fly the perpendicular and button-hook flight patterns.

These objectives were satisfied. A listing of accomplishments and data obtained follows:

a. Tests Accomplished

   (1) Tracked Gemini for six orbits.

   (2) Received and recorded VHF TLM for six orbits.

   (3) Downlink voice relay successful on five of six orbits.

   (4) Uplink voice relay successful on two authorized orbits.

   (5) Full HF duplex communications established.

   (6) Gemini VHF TLM data dumped to Corpus Christi.

   (7) Perpendicular pattern flown twice and button-hook flown four times.

b. Data Obtained

(1) Quantitative data recorded on magnetic tape.

(2) Quantitative data recorded on oscillograph, photorecorder, and event recorder.

(3) Qualitative data recorded on ship's logs.

A comprehensive analysis of the Gemini tests has been compromised by a lack of supporting data from the Government. No information has been received concerning spacecraft ERP or spacecraft position versus GMT, making extrapolation of Gemini data to Apollo impossible.

3.12.1.2 Operational History of Six Orbits

GT-12 Orbit 13

The spacecraft signal was acquired intermittently from 17:29:15 GMT to 17:31:20 GMT, when solid tracking began. Aircraft position at acquisition was 26-41N and 93-19W with an aircraft heading of 170°T. A perpendicular flight pattern was used. Telemetry data from GT-12 and Agena appeared to be good at the time. Downlink voice was barely readable. A 10-KHz IFBW filter had been experimentally installed in the voice receiver; also, the AFC appeared to react a bit slow for following short transmissions. The result was poor voice quality. The 10-KHz IFBW filter was replaced with a 100-KHz IFBW filter after Orbit 13 with good voice quality thereafter. Spacecraft voice was relayed to GSFC on 14.585 MHz with uplink reception on 17.552 MHz. Auto track was lost at 17:38:50 GMT; manual track was selected and continued to complete loss of signal at 17:40:40 GMT. Aircraft position at LOS was 25-28N and 93-52W with a heading of 170°T. Multipath was noted at acquisition and prior to LOS.

GT-12 Orbit 14

The spacecraft signal was acquired at 19:05:09 GMT. Aircraft position at acquisition was 23-25N and 93-30W with a heading of 339°T. VHF LHC was selected but tracking was very unstable so manual track was selected and continued throughout the data run. Telemetry data appeared to be good from both GT-12 and the Agena. There was very little downlink VHF voice traffic during the pass, but what was received was good quality. Downlink voice was relayed to GSFC on 20.390 MHz with uplink reception on 17.552 MHz. Loss of signal occurred at 19:13:50 GMT. Aircraft position at LOS was 24-30N and 93-40W with a heading of 339°T.

GT-12 Orbit 15

The spacecraft signal was acquired at 20:40:40 GMT. Aircraft position was 23-18N and 93-30W with a heading 283°T. Solid VHF LHC track was secured at 20:41:29 GMT with antenna position of 275° magnetic azimuth and +1 elevation. Telemetry data

appeared good from both GT-12 and the Agena. Downlink voice was relayed to MCCH via Cape Kennedy on 11.988 MHz with uplink voice received on 17.552 MHz. Two-way voice relay was started at 20:43:00 GMT with good communications up and downlink between MCCH and GT-12. Two-way voice relay was stopped at 20:46:48 GMT. The operator reported that tracking became intermittent during multipath, but auto track was continued until complete LOS at 20:51:20 GMT. Aircraft position at LOS was 24-12N and 93-00W with a heading of 97°T. Antenna position at LOS was 89° magnetic azimuth and +1° elevation. A button-hook pattern was flown during the Orbit 15 pass.

GT-12 Orbit 43

HF contact was made with Cape Kennedy with relay to GSFC and Houston. First contact was made simplex on 10.780 MHz upper sideband, with a change to 20.475 MHz upper sideband transmit and 17.552 MHz lower sideband receive for use during Orbit 43.

The Agena signal (240.2 MHz) was acquired at 17:25:25 GMT. Solid auto track was acquired on the Gemini at 17:29:08 GMT with good quality downlink voice and good TLM on both Agena and Gemini. Downlink voice was relayed to GSFC via Cape Kennedy on 20.475 MHz upper sideband. The ground track of the Gemini was such that the VHF/UHF antenna tracked into the upper elevation limit; however, loss of track at 17:35:43 GMT appears to be the result of an azimuth limit. The aircraft was in a turn to reverse its heading by 180° at the time of loss of track. This turn was continued and as soon as the aircraft had turned far enough to allow the antenna to be pointed at the spacecraft track, auto track was again restored (17:36:30 GMT). Some downlink voice and TLM data were received during the time auto track was lost. After reacquisition of auto track, voice and TLM data were good. Loss of auto track occurred at 17:38:40 GMT. Complete LOS on the Agena occurred at 17:35:20 GMT. Complete LOS on the Gemini occurred at 17:39:36 GMT.

Just prior to Orbit 43 pass, there was interference on 230.4 MHz, which was believed to be from the HF transmitter (20.475 MHz) connected to the trailing wire antenna. This antenna was not used during the pass, but after the pass it was reconnected and test counts were given without any indication of interference on 230.4 MHz. Further investigation was done on flights against the ground station with no evidence of interference. Interference from nearby frequencies was noted on 240.2 MHz; most of the interfering frequencies were airport control towers. A constant carrier with a high frequency tone was noted on 259.7 MHz standby frequency during Orbit 43 pass.

GT-12 Orbit 44

The Agena signal (240.2 MHz) was acquired at 19:03:05 GMT; for the first few minutes after acquisition there was interference from nearby frequencies. The Gemini signal (230.4 MHz) was acquired at 19:04:25 GMT, with solid auto track at 19:04:47 GMT at 264° magnetic azimuth and 0° elevation. Two-way voice relay between MCCH and the Gemini, via Cape Kennedy, was performed on HF (transmit 13.878 MHz upper sideband and receive 17.552 MHz lower sideband). Two-way voice relay was started at

19:08:16 GMT and stopped at 19:10:56 GMT. Voice communications both ways were 5X5 with the only comment being that MCCH found the receiver noise, that was present when the spacecraft was not transmitting, to be objectionable. The ground track of the spacecraft was nearly over the aircraft OSP with the antenna reaching a maximum elevation of 74° at 19:09:03 GMT. A momentary loss of track was experienced on LHC at 19:09:30 and at 19:10:15 GMT. RHC track was selected at 19:11:20 GMT with solid tracking. Loss of Agena signal occurred at 19:14:11 GMT. Momentary loss of Gemini signal occurred at 19:13:35 GMT, with complete LOS at 19:15:06 GMT. TLM data appeared to be very good and downlink voice received in the aircraft was also very good. Data quality has been determined to be good almost from the time of signal acquisition. The data quality was poor from the middle to the end of the run. The reason has not been determined, but appears to be caused by high multipath.

After post-mission calibration was completed, a data dump run was made toward the Corpus Christi telemetry site. A carrier with no data was transmitted for use in acquisition and was acquired by Corpus Christi at 19:24:58 GMT. Data dump was started at 19:47:00 GMT. Gemini predetection combined down-converted telemetry data from Telemetry Receiver 2 was dumped. The ground station indicated that the TLM data looked good, after the multipath period ended, except that some of the high frequency components were missing. Data were error-free of 4 minutes. The decommutation equipment on the ground was set to reject data if one error was present. The ground station operators indicated that the data looked good even when the decommutation equipment found an error. Data dump was stopped at 19:57:00 GMT. The quality of the dumped data appeared, for a time, to be better than the original tape it was dumped from. This proved to be the result of tape playback incompatibility (apparently an ever-present NASA network problem).

GT-12 Orbit 45

The Agena signal (240.2 MHz) was acquired at 20:38:15 GMT, with the Gemini signal (230.4 MHz) being acquired at 20:38:28. Solid auto track on VHF optimum tracking mode began at 20:39:05 GMT at an antenna azimuth of 276° magnetic and 0° elevation. Downlink Gemini voice was relayed to GSFC via Cape Kennedy on HF (transmit on 14.585 MHz USB and receive on 17.552 MHz LSB). Voice quality was good during the pass. The point of closest approach occurred at 20:44:30 GMT with the antenna reaching 88° in elevation. The aircraft had to make a high rate of turn to keep the antenna from reaching its limits. Loss of the Agena signal occurred at 20:49:18 GMT. Loss of solid track occurred at 20:49:30 GMT at 98° magnetic azimuth and 0° elevation. Complete loss of signal occurred at 20:50:06 GMT. Telemetry data appeared to have some multipath at the beginning and end of the pass. The data have since been elevated and it appears that the reason for the poor data quality was high multipath, caused by the antenna tracking well below the target at the beginning and end of the pass. This condition could have been improved by manually tracking the spacecraft with the antenna elevation at +20° during the intervals of high multipath. Data quality during the center of the pass was good.

A post mission calibration was completed, and Orbit 45 data were dumped to the Corpus Christi telemetry site. Data were dumped from 21:11:50 GMT to 21:24:39 GMT. The ground station indicated that the data appeared to be good on a scope, but with dropouts on the decommutation equipment. Error-free data were received for three minutes.

3.12.1.3 Calibration Technique, Reduced Data

Time history graphs of antenna position and signal level are provided in Appendix II for orbits 13 through 15, and 43 through 45. A brief analysis is included with each graph in the Appendix.

Support of a Gemini mission occurred quite early in the Category II Test Program. Only partial instrumentation was available, and provisions for in-flight AGC calibrations were not on board. Also, optimum operating techniques for acquisition and tracking and WB recorder set-up had not been developed.

Preflight of A/RIA was performed on 11 November 1966. AGC voltages from the two tracking receivers had been instrumented and were calibrated. As previously mentioned, calibration cables were inoperative, so open loop calibrations were made.

Calibrations were made using a known output from the signal generator through a cable to the collimation tower. The radiated signal from the collimation tower was received by the A/RIA VHF/UHF antenna and ultimately used to calibrate the AGC voltage and establish known levels of deflection on the receiver signal level meter. Collimation tower-to-A/RIA space loss was determined by the substitution method. That is, once a known AGC voltage had been established on the differential voltmeter, the output of the PMEE signal generator/attenuator was fed to the A/RIA directional coupler instead of through the collimation tower. The attenuator level was then adjusted until the level of AGC voltage was the same as had been established by using the collimation tower. The difference in power attenuation required to do this is the open loop space loss, thereby converting all calibration to the A/RIA directional coupler.

The power levels and signal level meter readings established by the open loop calibration were then used in-flight to establish calibration levels. During in-flight calibrations the signal generator was patched through the multicoupler into the receivers to be calibrated, using the signal level meter to determine when a signal, equal to that which had been used during preflight, was being injected. This method of calibration neglects drift in the system because it bypasses the preamplifiers, but was considered to be the best method available at the time. In view of the inaccuracies involved, the graphs being presented for the Gemini mission are qualitative only.

The tracking receiver AGC time constant selected was 10 milliseconds. It has since been determined that 1 millisecond is preferred when in a multipath environment because it allows the sum channel AGC to more nearly follow the multipath fades.

The telemetry receiver AGC time constant in use at the time was 100 milliseconds. It has since been determined that 1 millisecond is the preferred setting since a shorter time constant allows the receiver gain to compensate for multipath fades.

With regard to the signal level graphs for the Gemini mission provided in Appendix II, the multipath amplitudes shown are direct readout from the oscillograph. Because the 10-millisecond AGC time constant limits the AGC frequency response to 100 Hz, and because the galvanometer flat frequency response (see Multipath Amplitude Correction Curve, Section 3.2.1) is 30 Hz, the multipath fade amplitude is greater than that shown. AGC calibrations were made before and after each orbit.

3.12.1.4 Preliminary Analysis

Six orbits were covered on two flights by the A/RIA test aircraft. Analysis of data indicates that Orbits 44 and 45 represent two cases. There is related multipath fading based on antenna pointing angles, with the quality of received telemetry data determined from sync dropouts. For Orbit 45, good data was recorded during the center of the pass only, while the first half of Orbit 44 provided good data almost from the horizon.

Estimates of the trajectory of the reflection point for the two passes indicate that during the Orbit 44 pass, the reflection point was located over land for approximately the first 75 seconds from horizon time, while on Orbit 45 this duration was only about 25 seconds. Reflection from the land surface is assumed to produce considerably less reflection than from the sea.

The portion of the pass during which the multipath was reduced may have had an effect on the tracking performance of the antenna. Multipath has been found to cause a suppression of the elevation angle output of the tracking receiver due to non-linearity associated with the sum channel threshold. During the first half of Orbit 44, the antenna elevation followed the target quite well (see Figure 101) while Figure 102 shows that during Orbit 45 the antenna axis remained near the horizon except when the spacecraft elevation exceeded about 20°.

With the antenna directed toward the horizon, the potential reduction in multipath fading due to antenna angular selectivity is lost. Figures 103 and 104 show that estimated signal strengths, at the bottom of the multipath, fade for Orbit 45, as calculated for vertical and horizontal polarization, neglecting divergence factor. The curves indicate estimated values both for the actual A/RIA antenna elevation angles, as well as predicted values assuming that the antenna had been held at an elevation angle of $+20^{\circ}$ during those portions of the pass when the true target elevation angle was below $+20^{\circ}$. Vertical polarization (Figure 103) shows considerably less improvement for up-tilting in the region of Brewster's angle as a result of the reduction of reflection coefficient at these angles.

It is difficult to estimate the actual improvement that up-tilting would have provided in terms of data quality for Orbit 45 since the orientation of polarization, or allocation

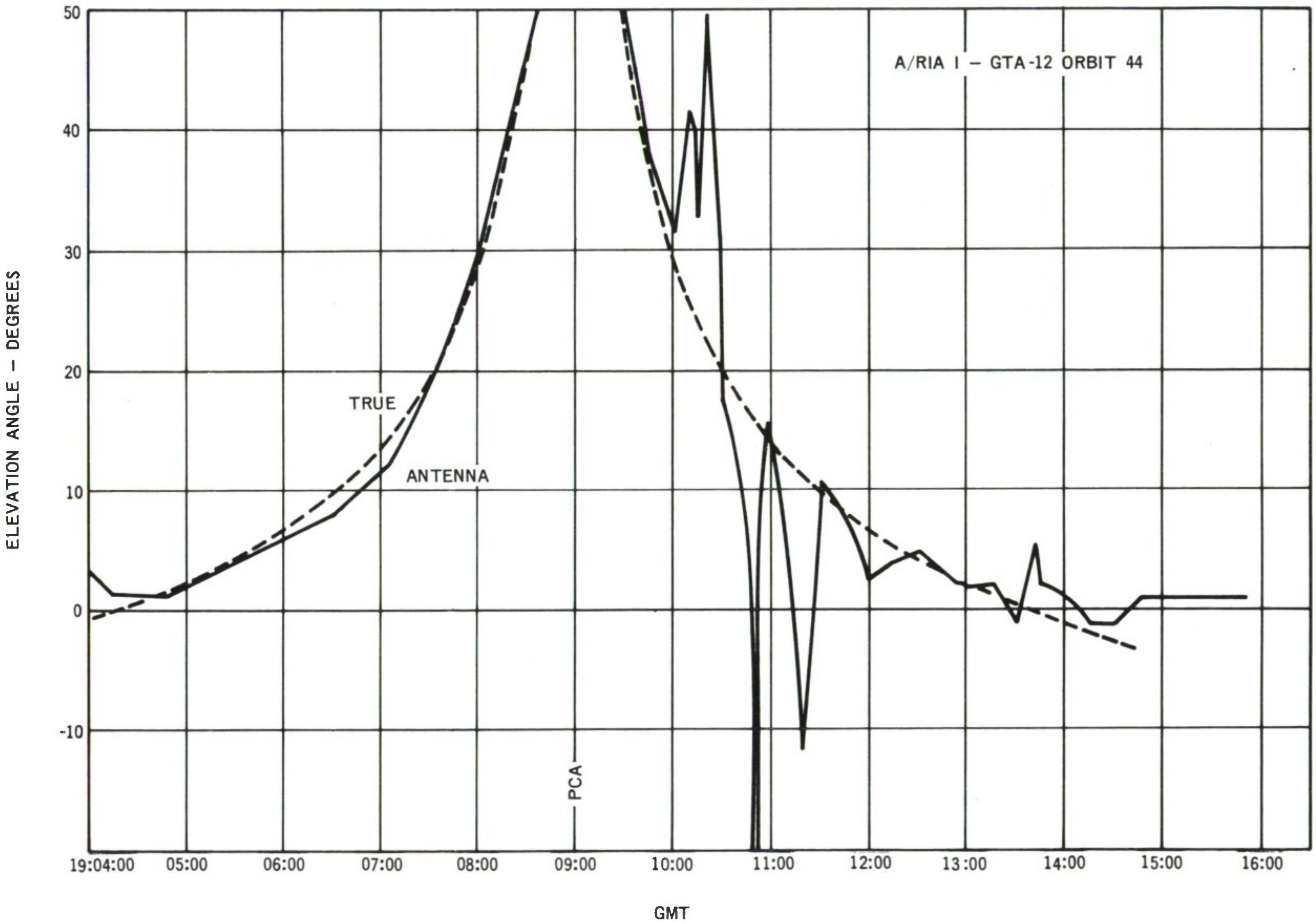


FIGURE 101. ORBIT 44 ELEVATION ANGLE

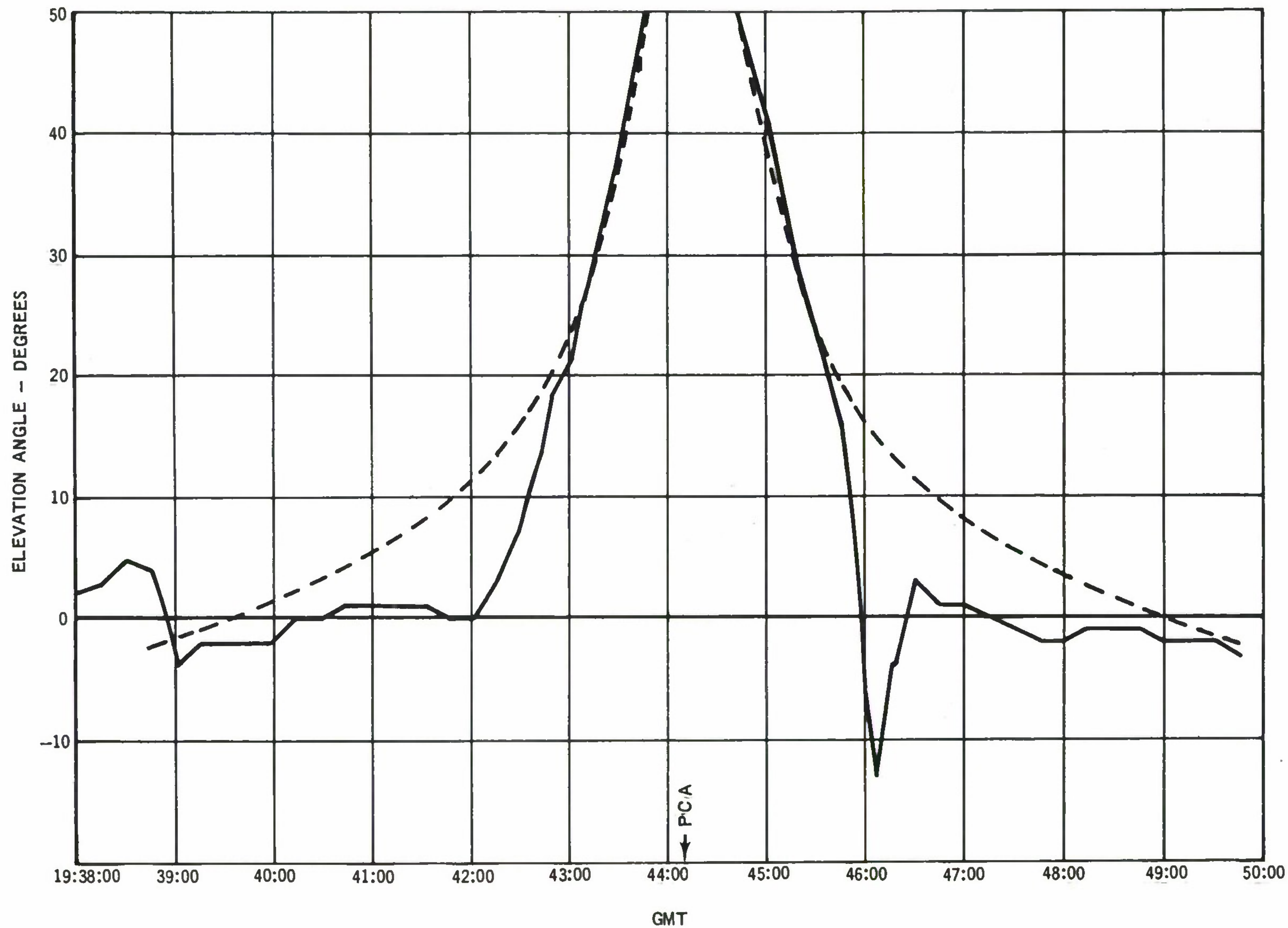


FIGURE 102. ORBIT 45 ELEVATION ANGLE

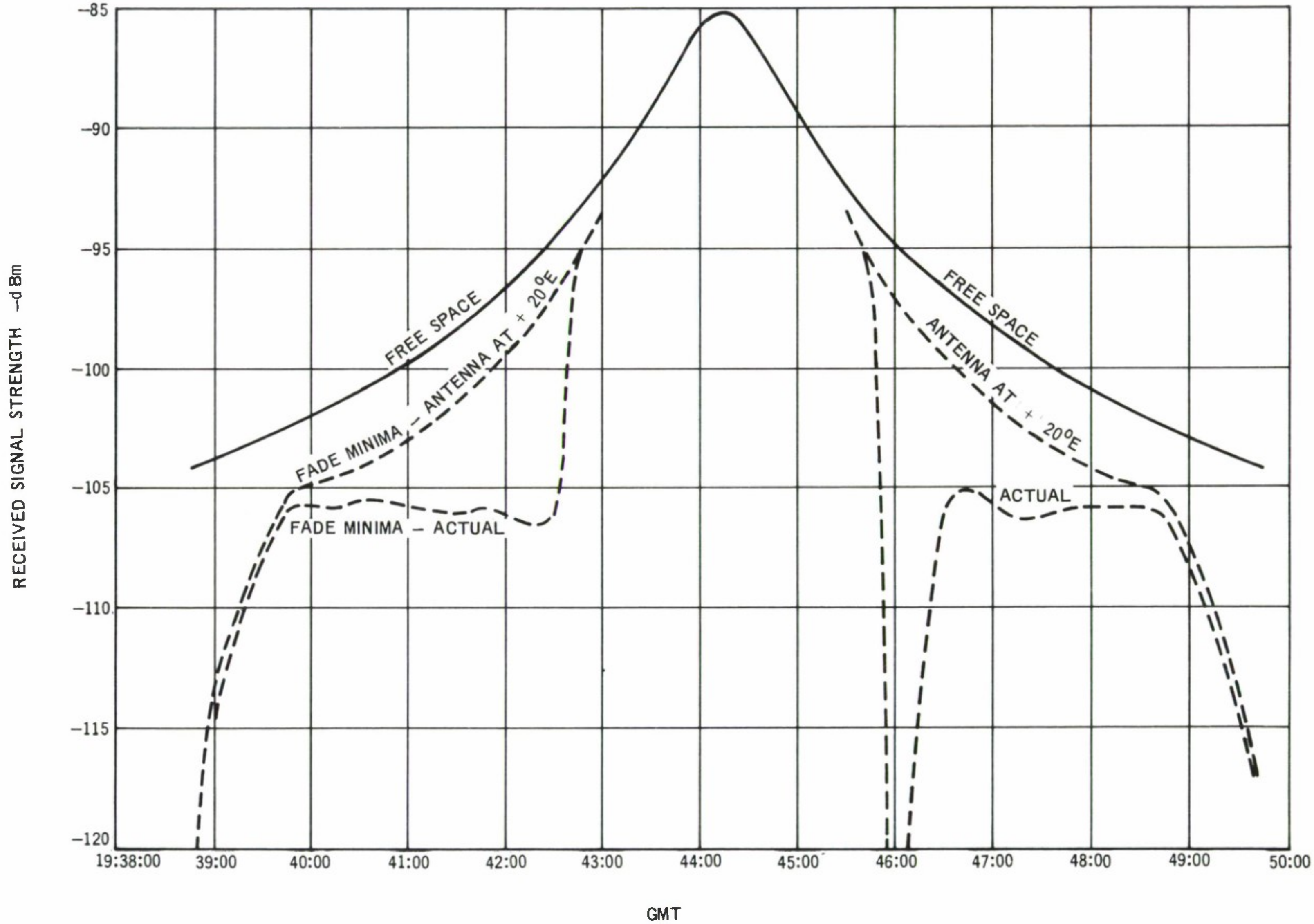


FIGURE 103. ORBIT 45 VERTICAL POLARIZATION SIGNAL STRENGTH

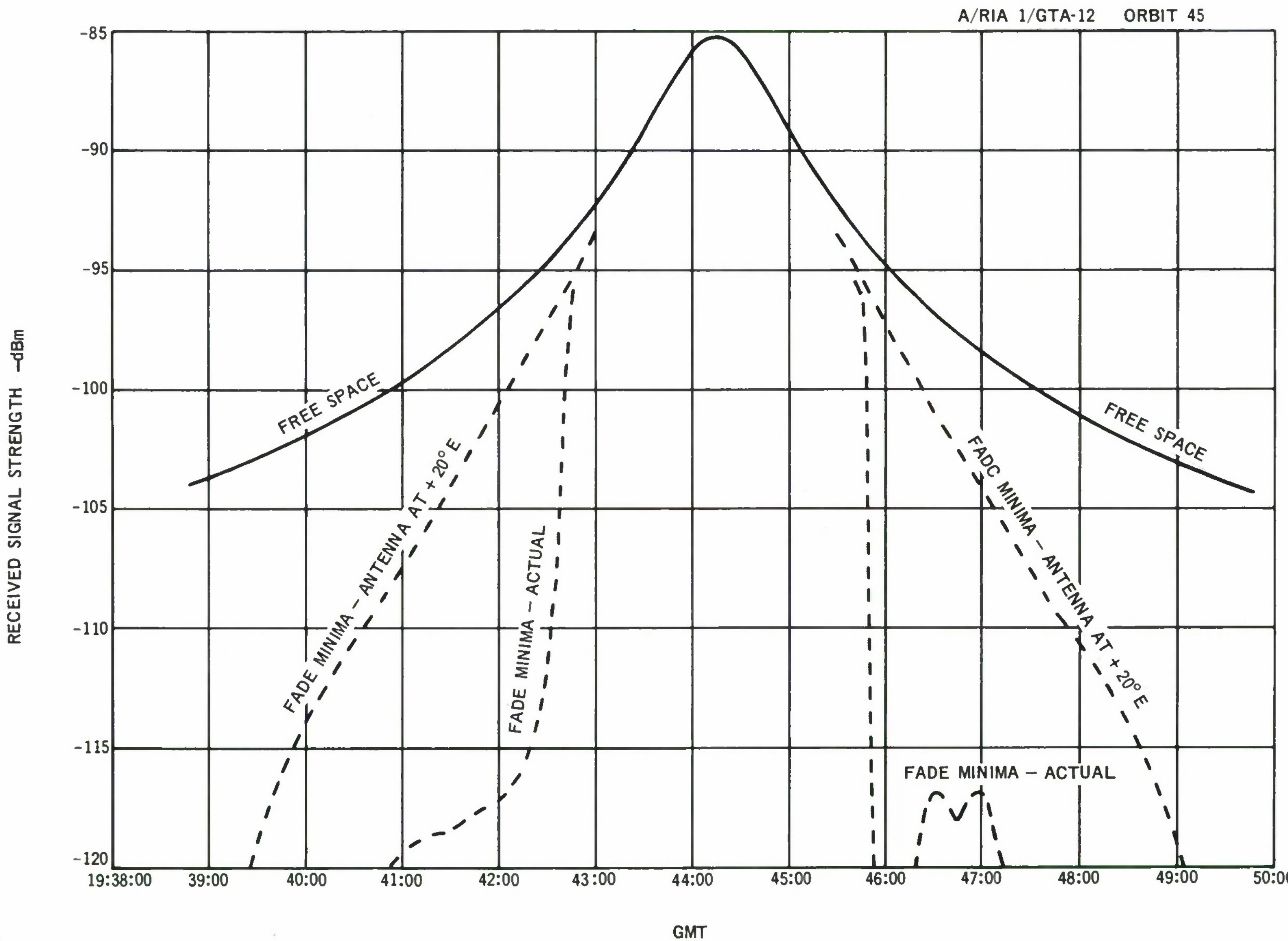


FIGURE 104. ORBIT 45 HORIZONTAL POLARIZATION SIGNAL STRENGTH

of received power between the polarization components, is now known. Referring to Figure 103, if the system threshold were considered to be at -105 dBm, the period of good data would be extended from about 3 minutes 15 seconds to about 8 minutes 30 seconds by up-tilting. If the received polarization were primarily horizontal, less improvement would have resulted from up-tilting, as indicated by Figure 104.

Figure 105 represents segments of a recording of main frame sync lock taken from Orbit 45 (RHC post detection, track 13), at 1 cm/sec. Time annotation is only approximate. Figure 105A shows the transition to good data corresponding to the rapid increase of signal strength, while Figure 105B shows the transition to poor data corresponding to the abrupt drop in signal strength shown in Figure 103 and 104. During the 197 seconds of the good data period, there were about 3.8×10^5 sync bits without error. Figure 105C shows the sync dropouts during a typical period of heavy multipath fading.

As a result, a number of alternate procedures were suggested to improve performance on future flights where only VHF is available. With regard to antenna elevation tracking, the tracking receiver IF bandwidth should be as narrow as possible; in this case 100 KHz instead of 500 KHz. If possible, the antenna should not be allowed to point below about $+20^{o}$ elevation when operating over the sea. This might be accomplished as follows:

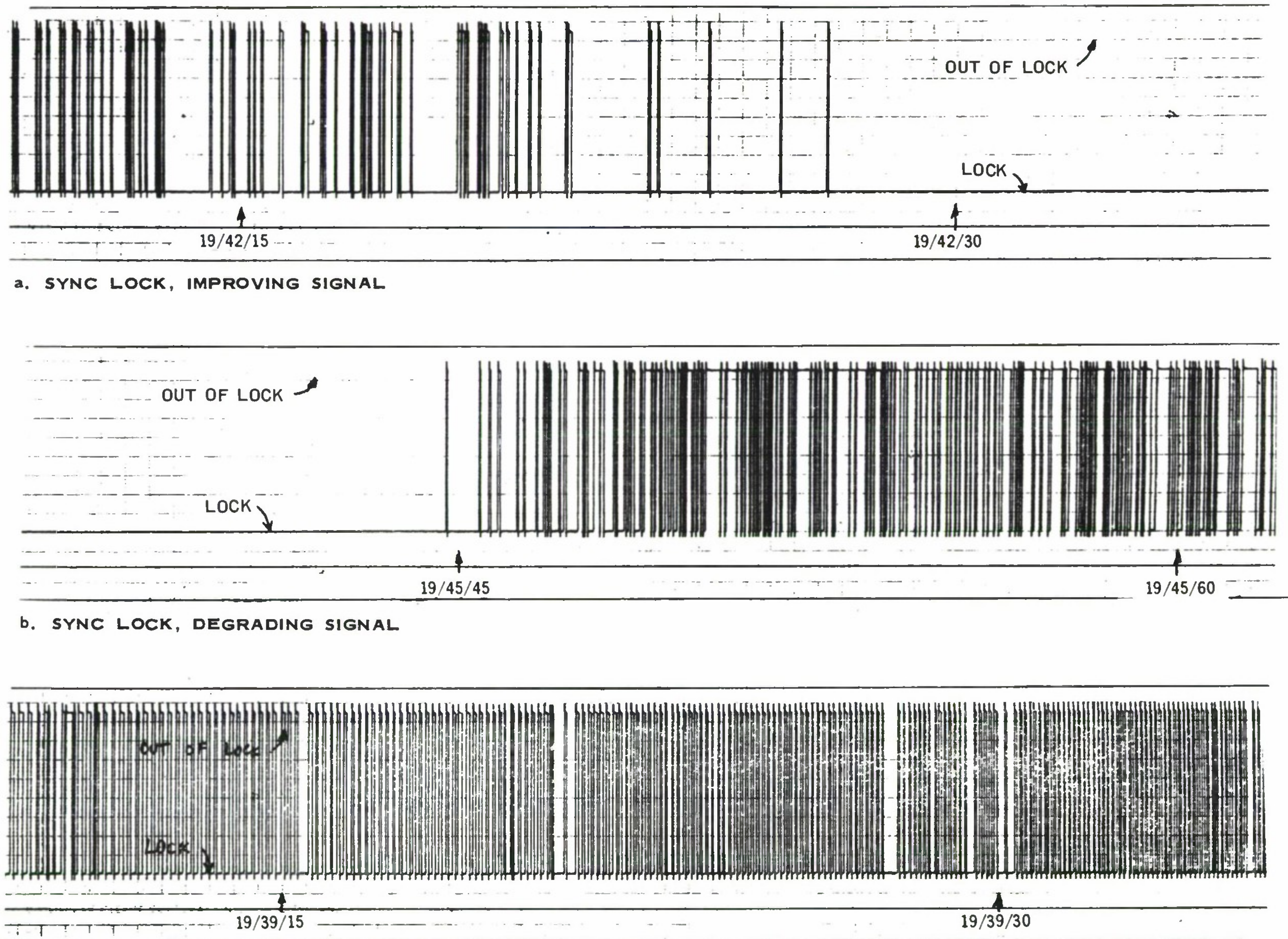
a. Align the antenna manually with the aircraft longitudinal axis in azimuth and $+20^{o}$ in elevation.

b. Fly the aircraft on the acquisition heading until the actual target elevation reaches $+20^{o}$; on Orbit 45, the azimuth angle would change less than 5^{o} during this period.

c. Auto track should then be initiated, and the aircraft flown to maintain the antenna axis aligned with the aircraft axis, approximately, during the center of the pass.

d. The aircraft should assume the final heading before the antenna elevation decreases to $+20^{o}$, at which time the antenna control should be returned to manual, and the $+20^{o}$ elevation angle maintained until LOS.

The data receiver bandwidth should be optimized to the radiated RF spectrum. For the Gemini Real Time format, a 100-KHz IF bandwidth would provide some improvement over the 300-KHz bandwidth used. Figure 106 indicates the relative measured improvement, using the PCM code test generator obtained from APL. Note that the absolute power levels shown in Figure 106 are not representative of the aircraft system, since the receiver was measured without benefit of preamplifier or bit conditioner.



a. SYNC LOCK, IMPROVING SIGNAL

b. SYNC LOCK, DEGRADING SIGNAL

c. SYNC LOCK, HEAVY MULTIPATH

FIGURE 105. RHC POST DETECTION SYNC LOCK, ORBIT 45

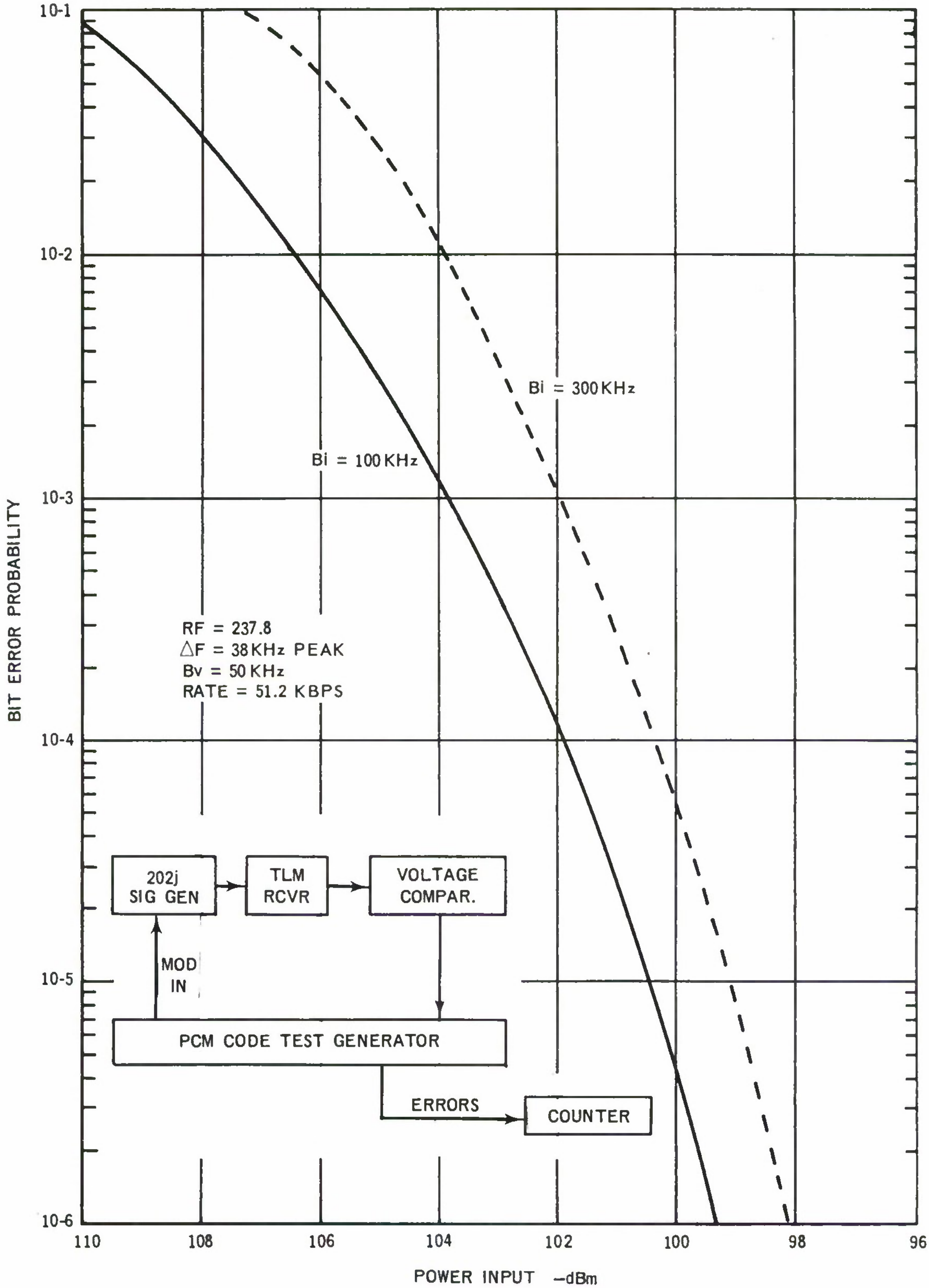


FIGURE 106. BIT ERROR PROBABILITY VS POWER INPUT

3.12.2 Ballistic Missile Mission

3.12.2.1 Summary of Test Results

The ballistic missile mission was a total success from an operational standpoint; however, the A/RIA system performance cannot be fully evaluated because of the limited data available. The mission was flown as planned, and the missile was automatically tracked from mid-trajectory to splashdown. Contractor personnel comments indicate that tracking was satisfactory despite unforeseen perturbations in the received signals. Telemetry data were recorded throughout the period, and operator evaluations indicate that the data are acceptable. Reduced instrumentation recordings were excellent and provide a continuous chronological sequence of happenings from initial acquisition to splashdown.

The lack of information concerning the actual flight parameters of the missile precludes an in-depth analysis of the mission. Information concerning the actual flight profile of the missile versus GMT is required to determine tracking performance. The results of the reduction and analysis of recorded telemetry data are required to evaluate the capability of A/RIA to receive and record telemetry data. No recommendations for improving performance on future ballistic missile missions, or extrapolation to Apollo, are possible with the minimal data available. Further, no results are available on the extensive teletype tests that were performed with AFETR during the period of the ballistic missile mission.

3.12.2.2 Test Results

On 2 March 1967, A/RIA 372 supported a ballistic missile flight. The purpose of the mission was to obtain data on the performance of A/RIA instrumentation in dynamic signal environment. The objectives of A/RIA's mission were to acquire and track the missile by mid-trajectory, record VHF telemetry data from the missile apex to splashdown, and obtain data to evaluate A/RIA system performance.

Analysis of Gemini data yielded the following two operational changes in tracking the ballistic missile:

a. The antenna was pointed 17° above the horizon at initial acquisition, as recommended in A/RIA Tech Note A0159, to reduce multipath effects. Gemini analysis had shown that the antenna had tracked below the target at low elevation angles. Data collected during the Category II testing at Tulsa had shown that a signal loss of only 1.5 dB would result from pointing the antenna above the target by 17°. This relatively small signal loss was taken in exchange for the predicted data improvement.

b. The AGC time constant on all receivers was set to 1.0 millisecond rather than the 10-millisecond time constant used on Gemini. This change was made to improve AGC control of the receivers under multipath (dynamic signals), and to permit the onboard instrumentation (oscillographs) to read the multipath frequency and amplitude more accurately.

A quantitative evaluation of these operational changes is not possible because no comparison of telemetry data at specific power levels received from Gemini and the ballistic missile is possible. The data available indicates that pointing the antenna up 17^{o} did reduce multipath as predicted.

Six time-history plots are presented as the results of the ballistic missile mission. The data for these plots were reduced from oscillograph records (receiver signal strengths, azimuth and elevation errors), photo recorder film (aircraft and antenna position), and event recorder records (discretes). Figure 107 is an overall mission plot and necessarily includes only average values for analog signals. Figure 108 through 112 are expansions of the following areas of particular interest:

a. Maximum range - initial acquisition

b. Initial AUTO TRACK

c. Re-entry and blackout

d. Splashdown

A brief discussion of each of these plots follows:

3.12.2.3 Overall Mission Profile (Figure 107)

The initial missile track was accomplished manually with the antenna held at $+17^{o}$ elevation to reduce multipath at or near the horizon. The records show very little multipath during this period. Auto track was initiated at approximately $+20^{o}$ elevation and continued with one exception until blackout. Auto track was resumed after blackout and continued up to splashdown.

The azimuth and elevation data on this plot were plotted at 3 to 10-second intervals. The signal levels of LHC and RHC track receivers were averaged and plotted at 15-second intervals. Significant events are noted on the plot.

Signal levels during the mission ranged from an average of -115 to -75 dBm, referenced to the A/RIA directional coupler. The antenna azimuth changed from an initial heading of 320^{o} magnetic at acquisition to 046^{o} magnetic at splashdown. Antenna elevation ranged from the preset $+17^{o}$ at acquisition to a maximum of $+50^{o}$ and back down to -7^{o} at splashdown. Short term variations in antenna azimuth and elevation, apparent up to 14:00:15 GMT, may have been the result of the two track receivers having a different channel null position. The large deviations between 14:00:15 and 14:00:45 occurred when the operator selected LHC and RHC tracking modes, respectively. The balance on auto track was in VHF/OPT mode; from 14:00:45 to splashdown the system was in VHF/OPT. It should be noted that the values on this plot only indicate trends, since the signals were changing dynamically throughout the period.

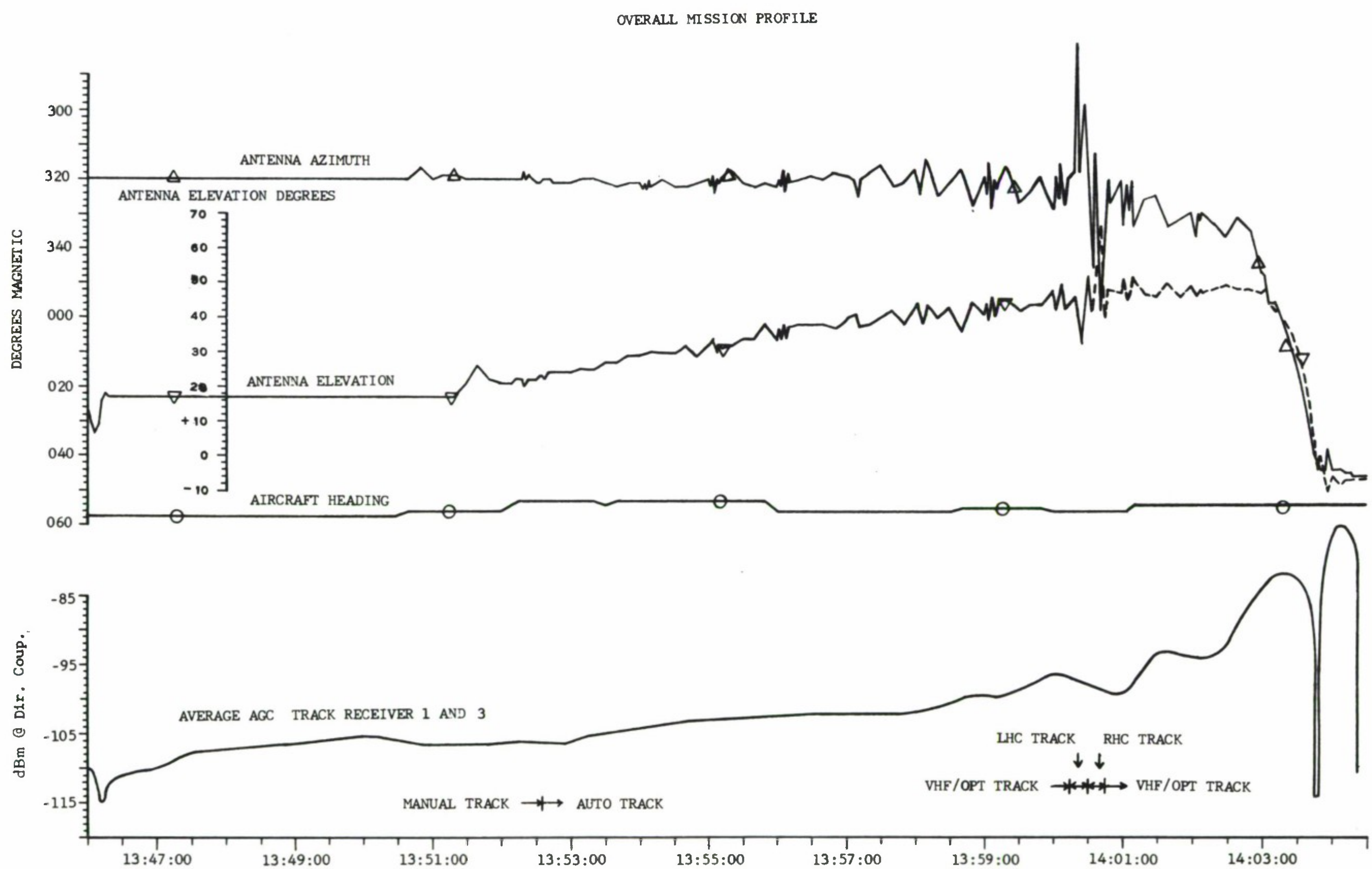


FIGURE 107. OVERALL MISSION PROFILE

3.12.2.4 Maximum Range, Initial Acquisition Plot (Figure 108)

This plot shows signal level characteristics during initial acquisition. The antenna was initially placed in manual track mode, with the elevation and azimuth values as shown on the plot. Initial acquisition by the RHC track receiver does not appear on this plot, but occurred at 13:46:47. The acquisition level of the LHC track receiver was -108 dBm at the A/RIA directional coupler. This is system threshold.

3.12.2.5 Initial Auto Track Plot (Figure 109)

This plot is an expansion of the 30-second interval when the antenna track mode was changed from manual to auto track. Two separate plots were made of this time period because of the complexity of the received signals. The action of the tracking combiner can be seen by observing the signal levels of the individual receivers and the combiner's selection of the track receivers.

After auto track was selected, the antenna azimuth and elevation changed slightly. The antenna azimuth was $320^{\circ} \pm 1^{\circ}$. The antenna elevation changed to $+20^{\circ}$ after auto track, and gradually increased to $+24^{\circ}$.

A definite pattern is evident in the received signal during this period. The pattern repeats every 8 seconds, with major nulls occurring at 8-second intervals. Minor nulls occur at 1.5-second intervals. Preliminary planning data from AFETR indicated that antenna nulls down to -21 dB were to be expected during this mission. The signal level on the LHC receiver during this interval is from 1 dB to 2 dB higher than the signal level on the RHC receiver. The maximum signal level on the LHC receiver is -101 dBm at the directional coupler.

3.12.2.6 Blackout Plot (Figure 110)

Figure 110 expands the time period of the re-entry and blackout portion of the missile flight. During this period all receivers broke lock and the tracking system tracked on rate memory for 2.5 seconds.

At 14:03:30 the signal level dropped to near break lock on all receivers. The received signals were changing dynamically during this interval, with all receivers reading momentary break lock three times before complete LOS at 14:03:45. High multipath is evident beginning at 14:03:37, when antenna elevation is down to $+20^{\circ}$. Multipath frequency before complete blackout was 10 to 11 Hz.

The multipath amplitudes shown are direct readouts from the oscillograph. Because the 1 millisecond AGC time constant limits the AGC frequency response to 1000 Hz, and because the galvanometer flat frequency response (see Multipath Amplitude Correction Curve, Appendix III), the multipath fade amplitude is greater than that shown.

During the 30-second interval from 14:03:25 to 14:03:55, antenna elevation changed from $+36^{\circ}$ to -11° while antenna azimuth changed from 9° to 50°. Antenna elevation

MAXIMUM RANGE, INITIAL ACQUISTION

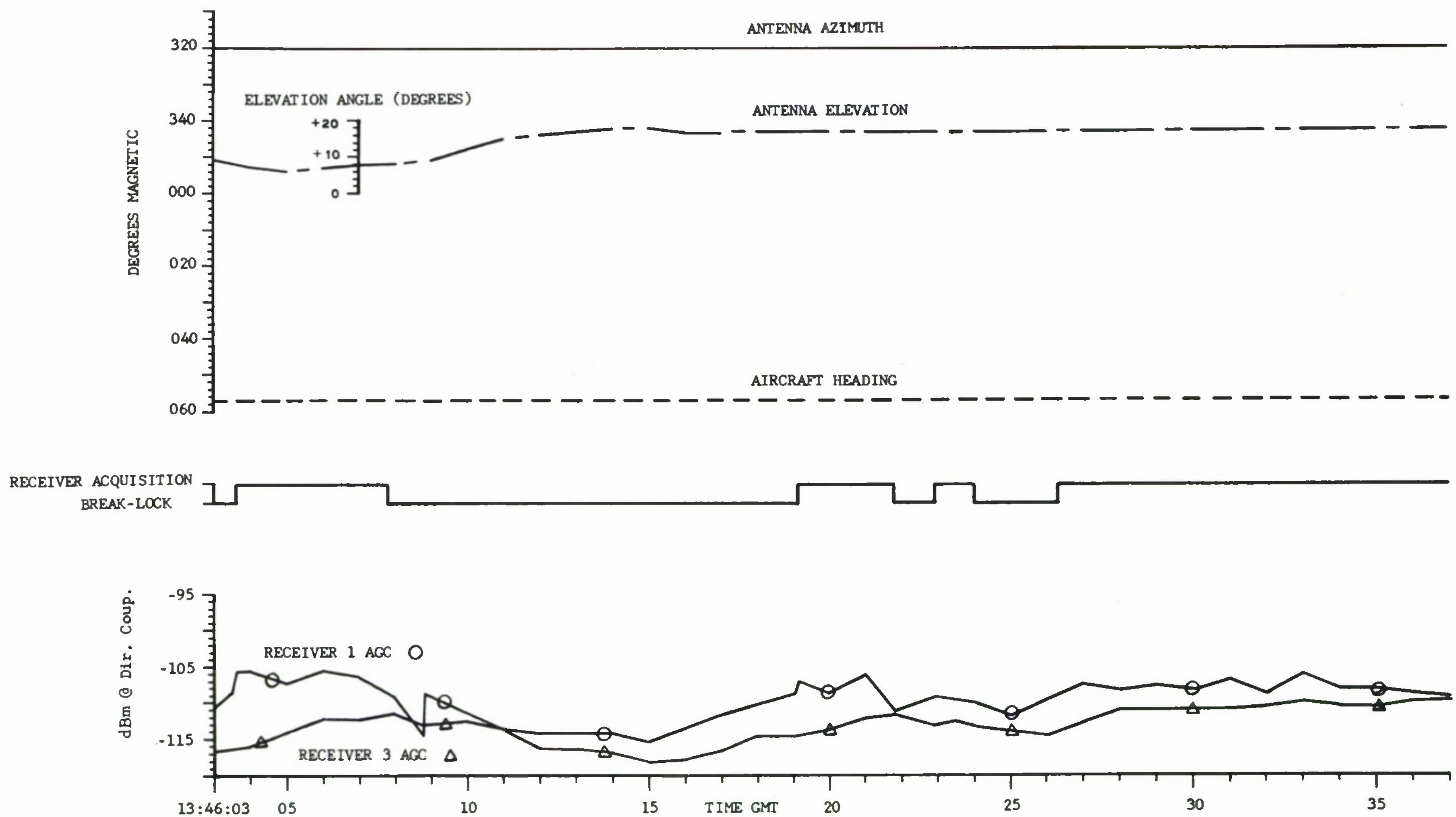


FIGURE 108. MAXIMUM RANGE, INITIAL ACQUISITION

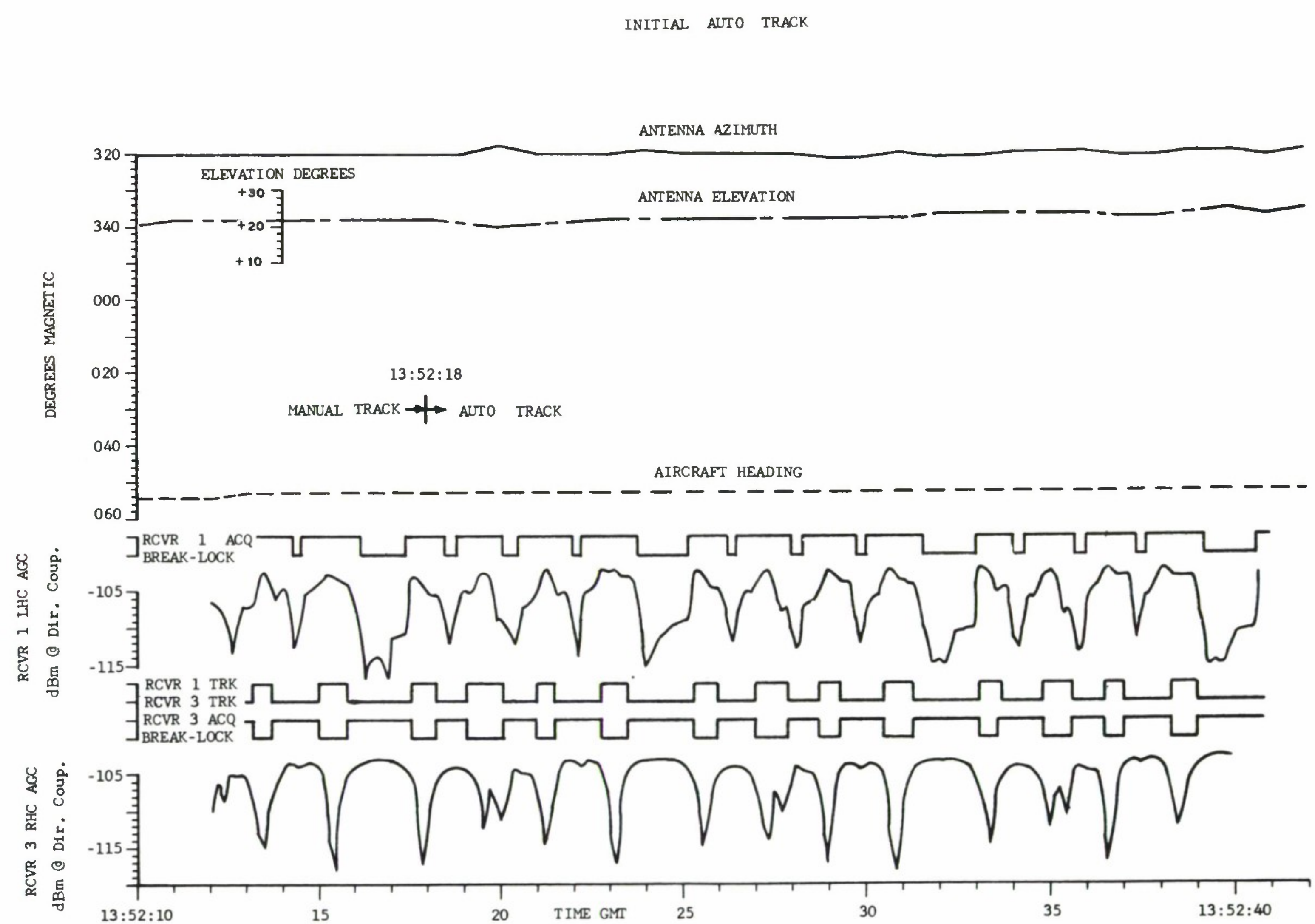


FIGURE 109. INITIAL AUTO TRACK

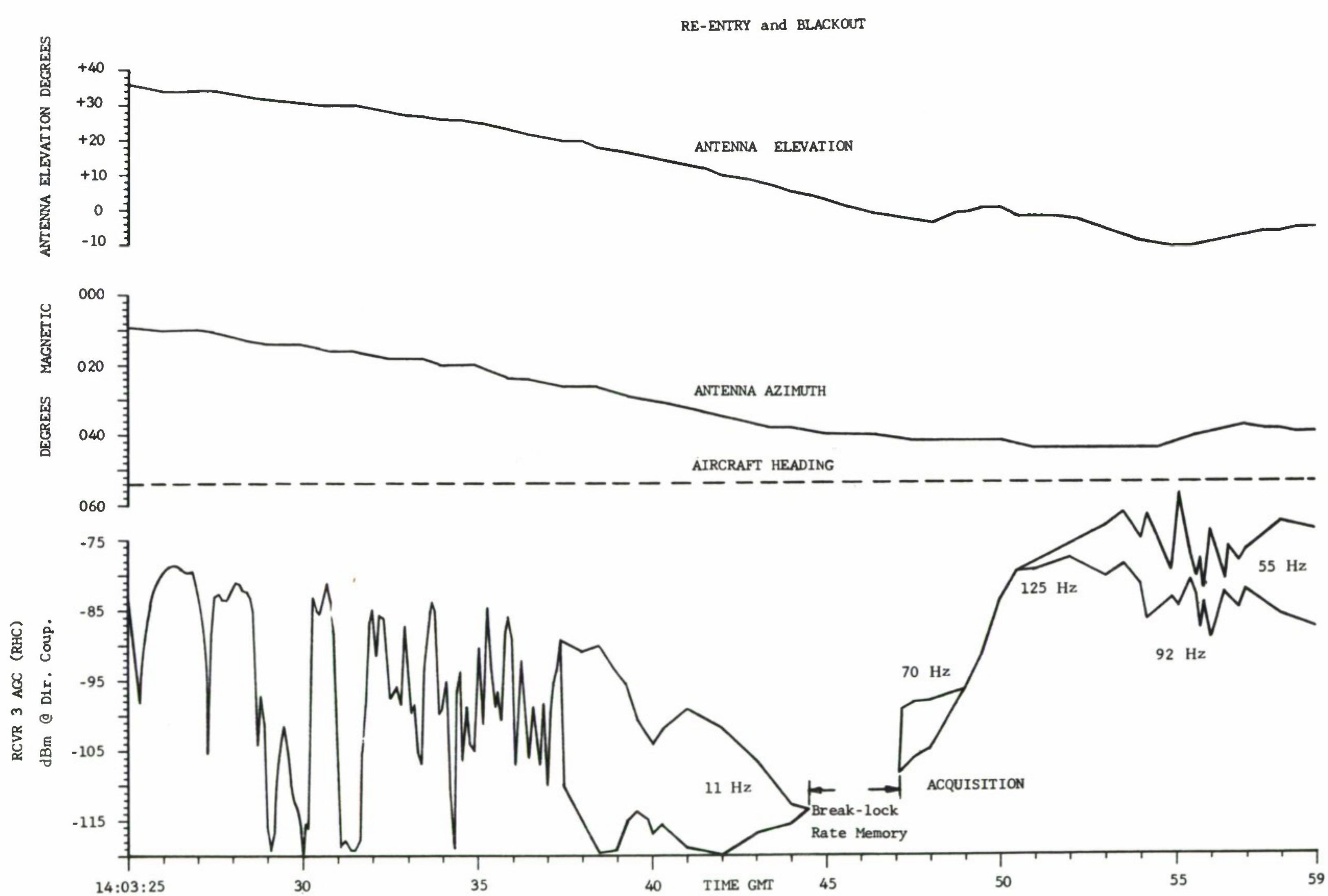


FIGURE 110. RE-ENTRY AND BLACKOUT

and azimuth during rate memory continued to change at the rate established prior to loss of signal. This is evident on Figure 110. The received signal level increased as the blackout period ended. Multipath frequencies of 55 to 125 Hz were recorded.

3.12.2.7 Splashdown Plot (Figures 111 and 112).

This plot is an extension of the blackout period and continues until splashdown and LOS. Signal level plots of the RHC and LHC receivers are shown separately to improve presentation clarity. During the period, the signal level measured from the LHC tracking receiver was approximately 5 dB higher than the signal level measured from the RHC receiver. These levels were between -66.5 dBm and -96 dBm. Multipath frequencies ranged from 52 Hz at 14:04:00 to 40 Hz at final LOS. Antenna azimuth and elevation changed slightly during this period. Elevation changed 2^{o} (from -6^{o} to -8^{o}) and azimuth changed 3^{o} (from 43^{o} to 46^{o}). Final LOS occurred on all receivers at 14:04:21.5. The tracking system switched into rate memory until manual track mode was selected by the antenna operator.

3.12.3 Extrapolation to Apollo

Based upon an analysis of Category II Flight Test Program results, and theoretical data derived from A/RIA technical notes, the following procedure is recommended for A/RIA operation against an Apollo CSM (Reference Tech Note A0141, Appendix III).

3.12.3.1 General Configuration

Acquire and Track

Configure the UHF tracking receivers for Unified S-Band, utilizing a 3.3 MHz IF bandwidth filter and a 1000-Hz tracking phase-lock loop bandwidth. Operate the receivers in APC mode, long loop, with coherent AGC. Configure the VHF tracking receivers for PCM/FM, with a 300-KHz IF bandwidth filter. Operate in the AFC mode. Configure the VHF receive system for circular polarization. Circular polarization on VHF has proven to have advantages over linear polarization, namely:

a. Redundancy is provided in the tracking and telemetry channels, regardless of the pointing angle of the antenna to the aircraft heading. Test results show that the VHF circular receive system has no discernible ellipticity.

b. Predetection combining of VHF data is optimized because the two channel signal inputs are essentially equal.

Telemetry

Configure the UHF signal data demodulators for either a 51.2-KBPS or 1.6-KBPS data rate, as required by the mission. Record Unified S-Band telemetry data in the post-detection mode, using an FM record module. The 1.024 MHz data subcarrier should not be recorded. Operate the wideband recorder at a speed of 60 ips. VHF

SPLASH-DOWN RECEIVER 3

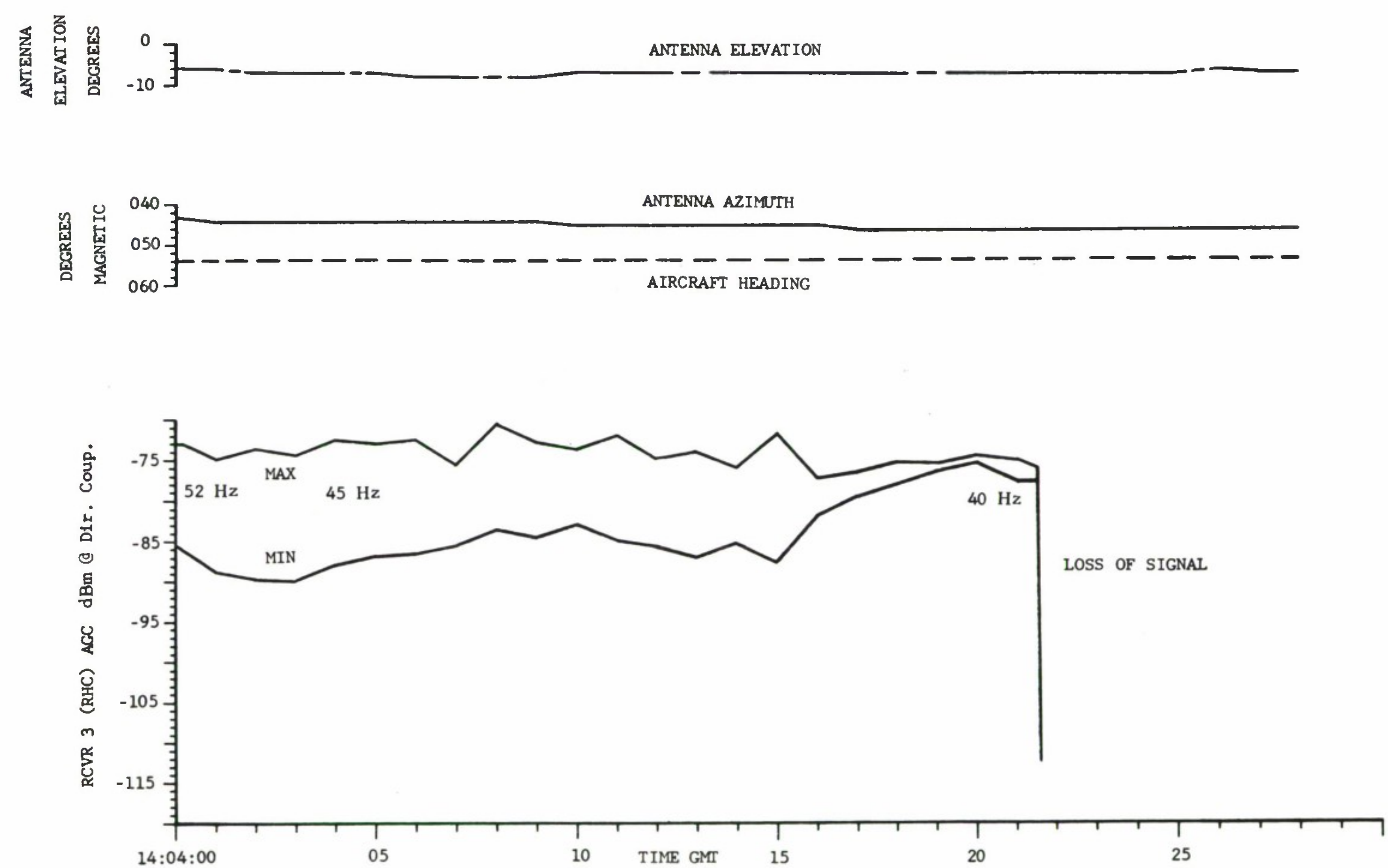


FIGURE 111. SPLASH-DOWN, RECEIVER 3

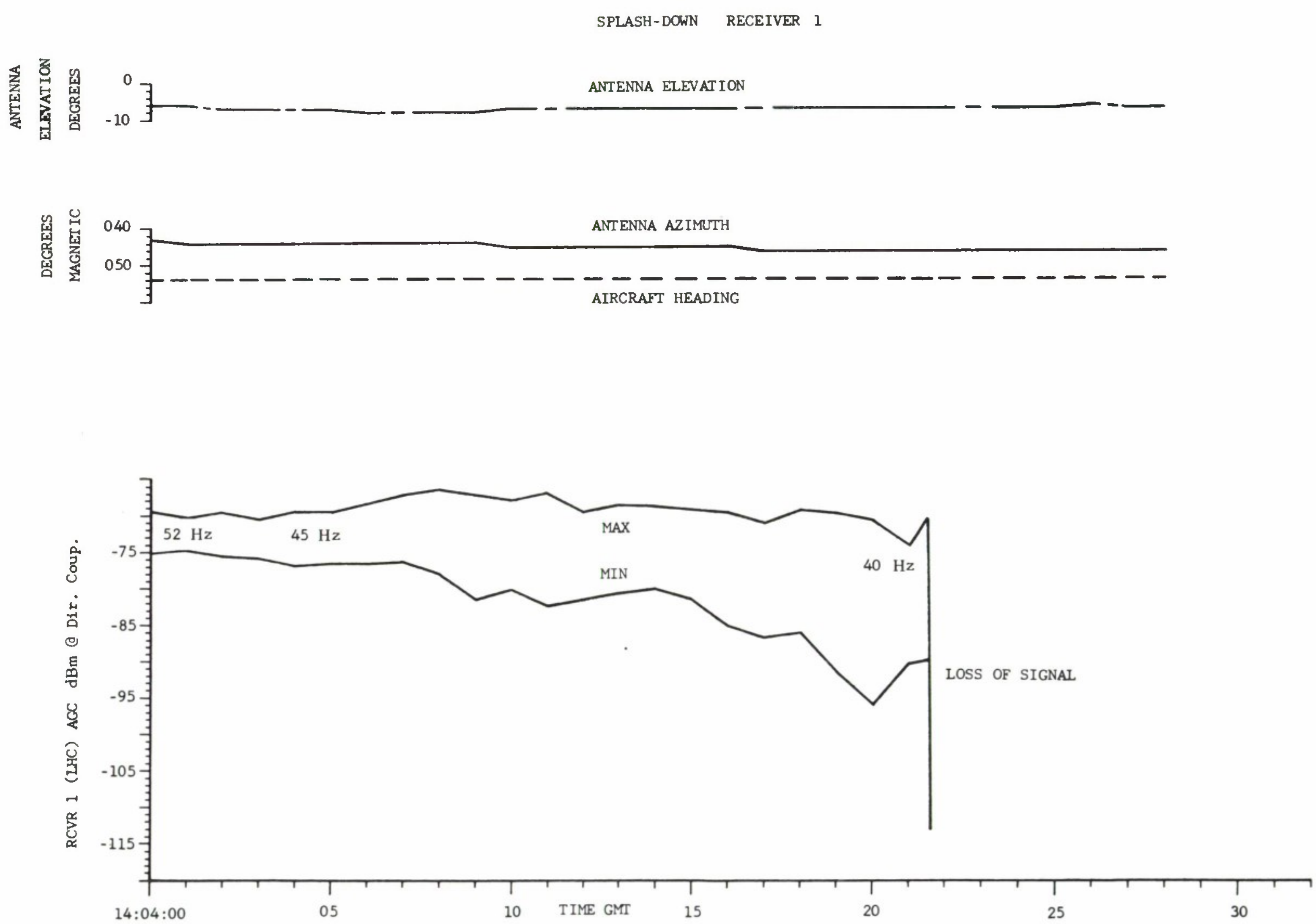


FIGURE 112. SPLASH-DOWN, RECEIVER 1

telemetry data from the 237.8 MHz link will be taken from telemetry receivers (rather than track receivers). Five outputs will be recorded: Channel 1 and Channel 2, predetection and post-detection combined. Record the post detected 51.2-KBPS through a 50-KHz video filter, and the 1.6-KBPS data through a 3-KHz video filter.

Voice

Record Unified S-Band voice on the audio recorder from Combiner 1. Record VHF voice from Combiner 2, and UHF/VHF combined voice from Combiner 3. Utilize a 30-KHz IF bandwidth filter with the VHF voice receiver. In addition, record the MCC and HF voice.

HF

Transmit HF voice and TTY on separate transmitters, if possible. TTY will use four-tone diversity for transmit and receive. The selection of antennas is at the discretion of the operator.

Data Dump

Configure the VHF and UHF for PCM/FM operation. Patching would depend upon mission requirements. The Unified S-Band data, recorded post-detection, can be patched to either one or both transmitters. The VHF data, recorded either predetection or post-detection, can be patched to either/or both transmitters.

3.12.3.2 Initial Acquisition & Tracking

Based upon Analysis A, the CSM would be acquired at a range of 1200-nm on UHF. Sector scan with automatic acquisition is recommended. The scan parameters should be: (Ref: A/RIA Tech Note A0146).

Azimuth sector:	$\pm 4^{\circ}$
Azimuth rate:	$2.5^{\circ}/\mathrm{sec}$
Sweeps:	2
Elevation increment:	3.2°

The receiver frequency acquisition parameters are defined in A/RIA Tech Note A0138. If accurate pointing data are available, initial acquisition should be attempted in UHF/OPT mode. High multipath on VHF at low elevation angles would preclude the use of the UHF/VHF OPT mode, since the varying VHF signal may cause the antenna to point off of the target. This would compromise a UHF signal acquisition. At a range of 1200 nm, expected tracking margins are as follows:

UHF	7.8 dB (Analysis A, end of section)
VHF	0.0 dB (Analysis B, end of section)

Category II flight test results indicate that the UHF system will track to a stability of $\pm 0.5^{\circ}$. With the receivers properly phased, tracking accuracy should be to $0^{\circ} \pm 0.5^{\circ}$. Once the spacecraft reaches an elevation angle of approximately 20°, the track mode should be changed to UHF/VHF OPT. This will provide VHF backup if UHF tracking is lost.

If UHF acquisition and tracking is not possible, VHF tracking could be used. Based upon Gemini and ballistic missile experience, it is recommended that the target be tracked manually to an elevation angle of approximately $+20^{\circ}$. Auto track would then be initiated at $+20^{\circ}$ and tracking continued in this mode until the elevation angle again decreases back to approximately $+20^{\circ}$ toward the end of the pass. Following, the target would be manually tracked to the horizon. To optimize reception of VHF data, and minimize multipath, it may be desirable to keep the antenna at least 17° above the horizon. This is reasonable since the received VHF signal level required for acquisition is above that required for good telemetry data. If VHF signal acquisition is set to occur at 6 dB SNR predetection, and man-made noise is low, it would be possible to be receiving good data and yet not be able to lockup the tracking loop.

3.12.3.3 Data Interval

3.12.3.3.1 VHF

Based upon Analysis D, the VHF telemetry data interval could begin at initial acquisition, where a +7.1-dB margin is predicted for 51.2 KBPS and a +36.8-dB margin for 1.6 KBPS. These margins are derived from a predetection SNR of 6 dB. Because of the relatively steep FM improvement curve on both data rates, the output SNR margin would decrease to 0 dB with a decrease in the predetection signal of approximately 3 dB (51.2 KBPS) or 5 dB (1.6 KBPS). If the system is tracking on UHF from the horizon, data quality could be improved by the use of electrical beam tilt. Figures 113 through 118 were derived to predict the optimum beam tilt position for Apollo coverage. Figure 113 is a plot of the expected multipath seen by the vertical channel. Received signal power at the directional coupler is plotted versus time for the data interval. Three curves are shown, namely: the reflected wave in phase with the direct wave, the reflected wave 180 degrees out of phase with the direct wave, and the free space signal level. Figures 114 through 118 are similar plots for horizontal polarization for electrical beam tilts of 0°, 11°, 16°, 20°, and 23°, respectively.

The multipath rejection for the various beam tilt angles was calculated based upon the pattern measurements presented in Test 12 of Section 3.4.1.5. The calculations were made at 10-second intervals over the 530-second injection burn period, and are based upon over water reflections with the divergence factor neglected.

The free space level, which does not include direct signal attenuation due to beam tilt, is superimposed on the curves for comparison to the maximum and minimum signal level envelopes (in phase and out of phase curves, respectively).

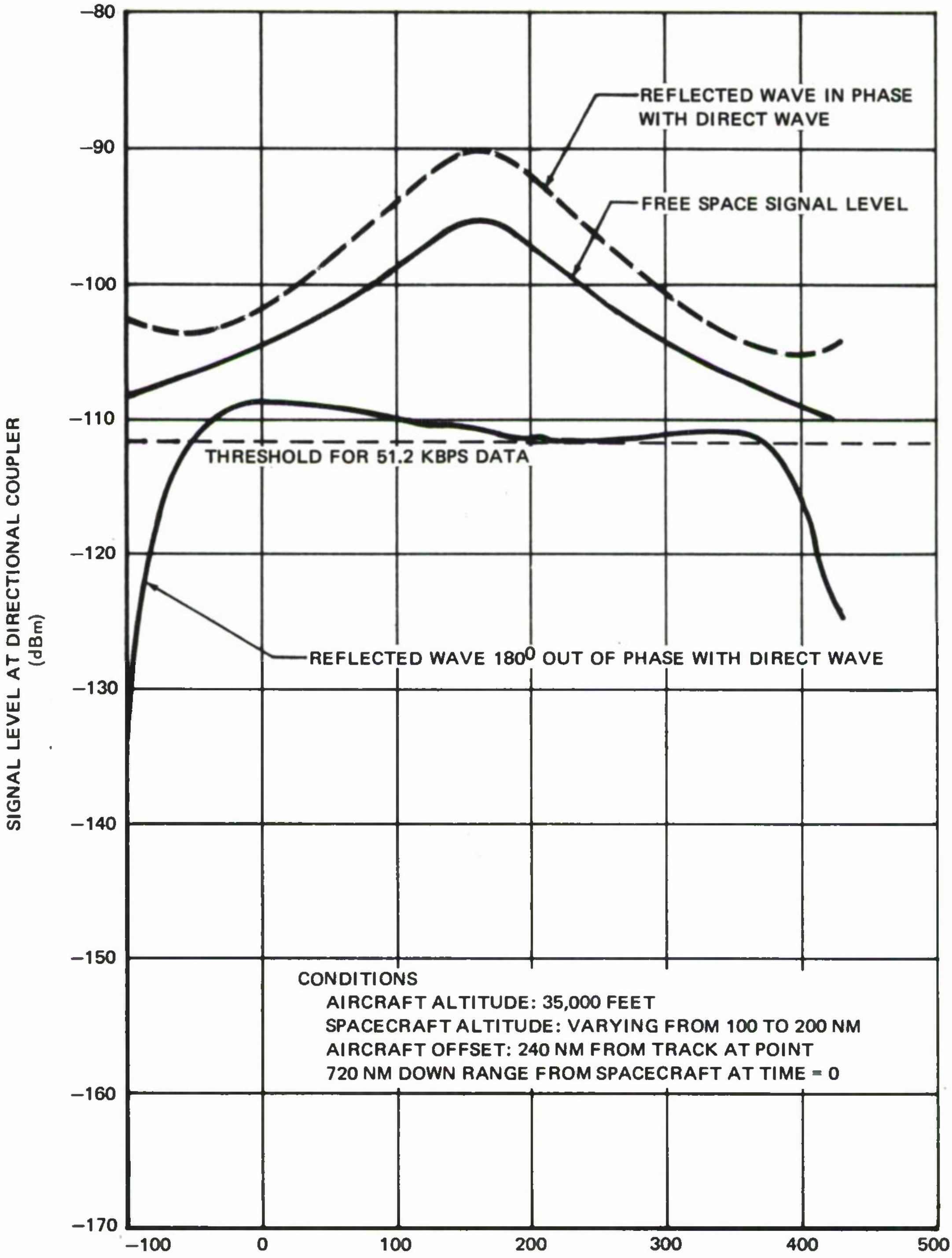


FIGURE 113. MULTIPATH EFFECTS – VERTICAL POLARIZATION

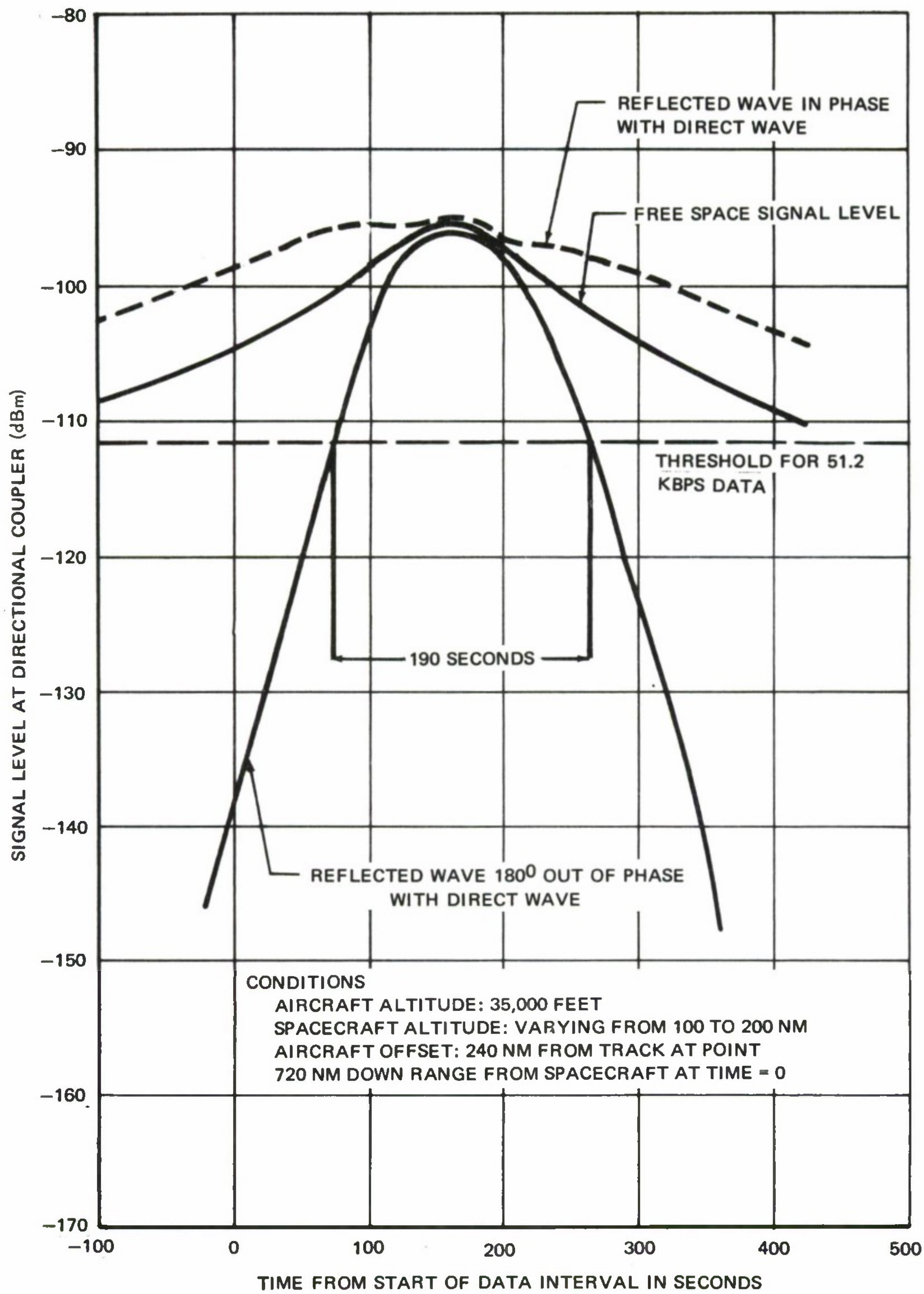


FIGURE 114. MULTIPATH EFFECTS – HORIZONTAL POLARIZATION – 0° BEAM TILT

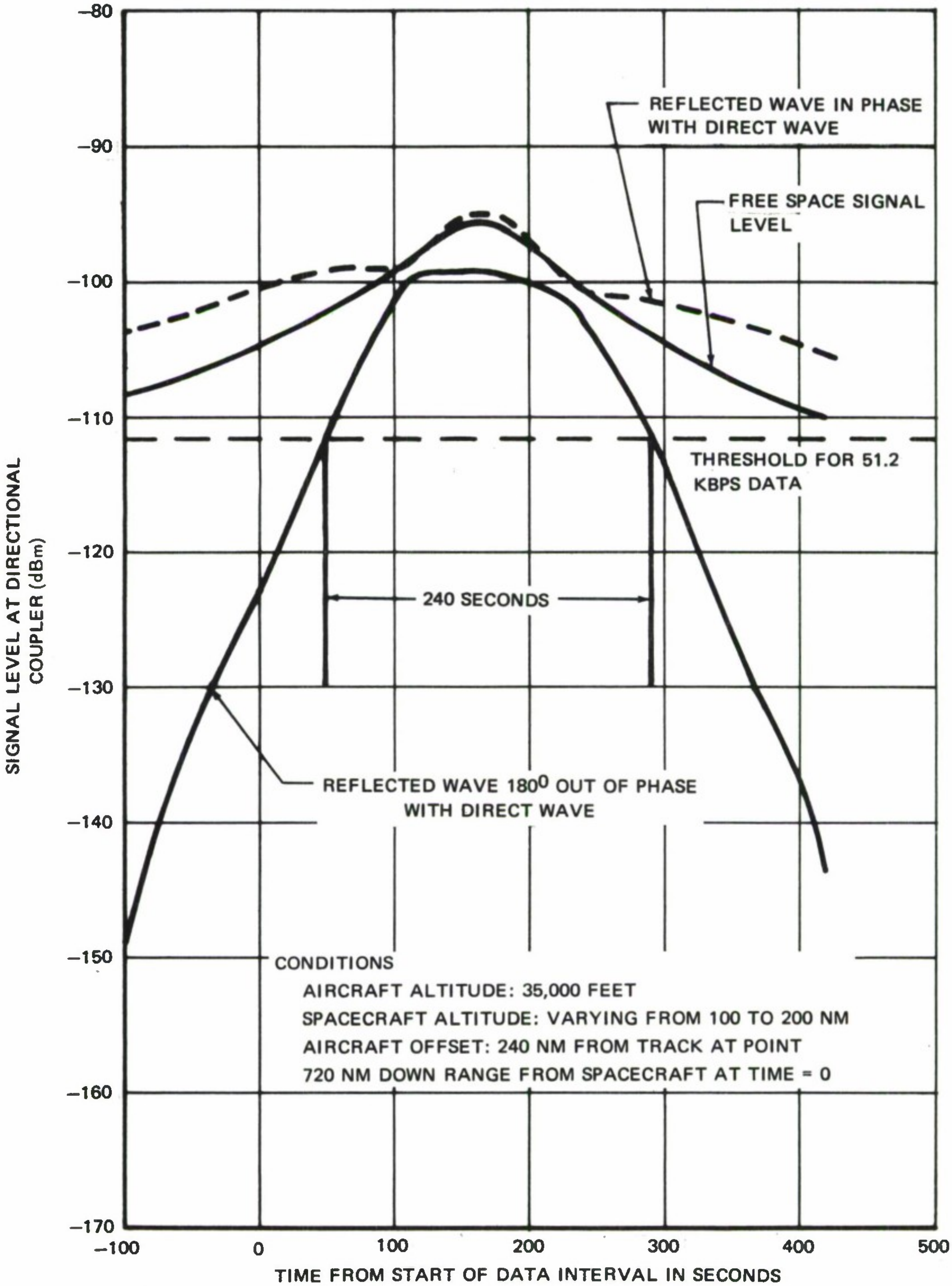


FIGURE 115. MULTIPATH EFFECTS – HORIZONTAL POLARIZATION – 11° BEAM TILT

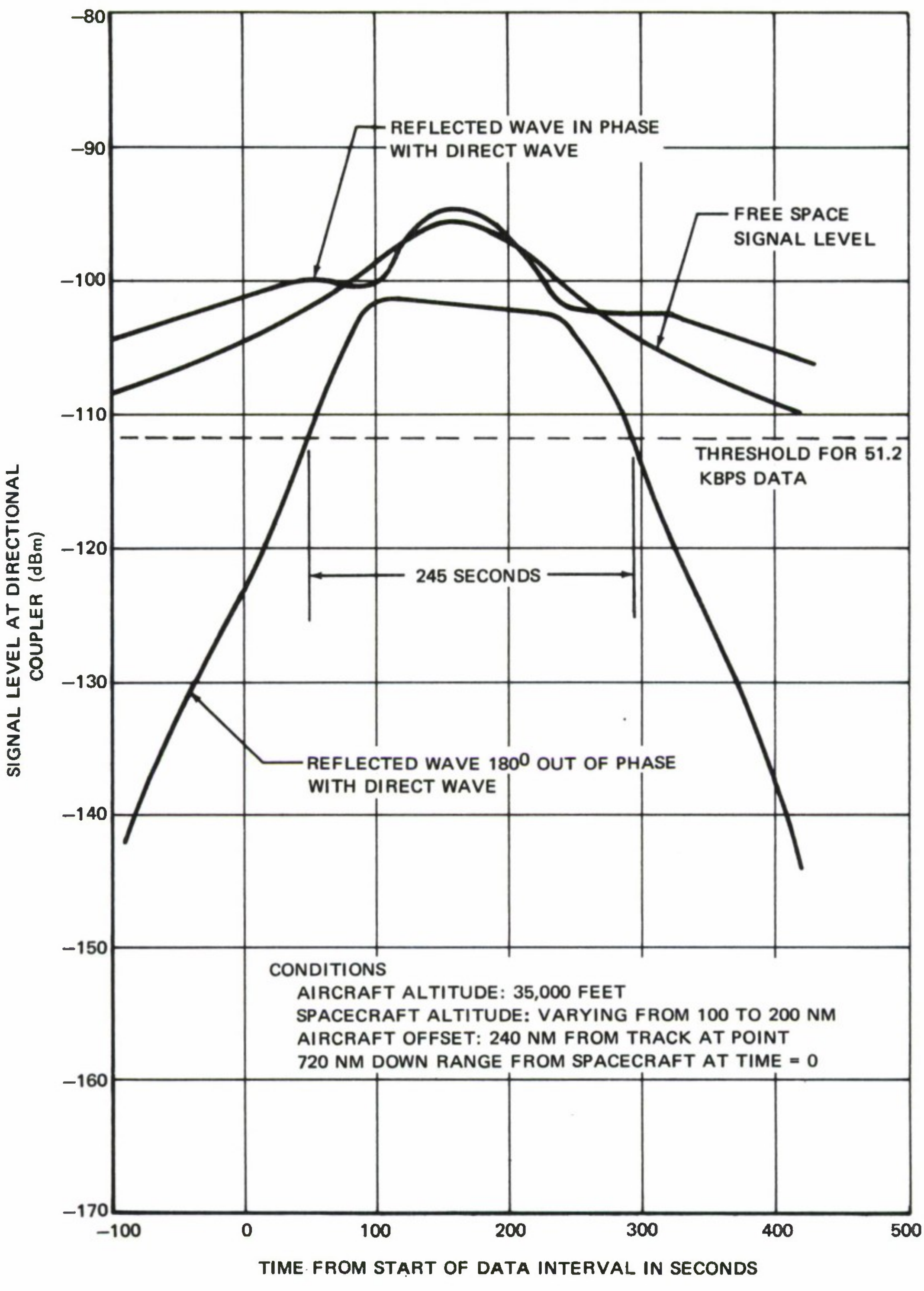


FIGURE 116. MULTIPATH EFFECTS – HORIZONTAL POLARIZATION – 16° BEAM TILT

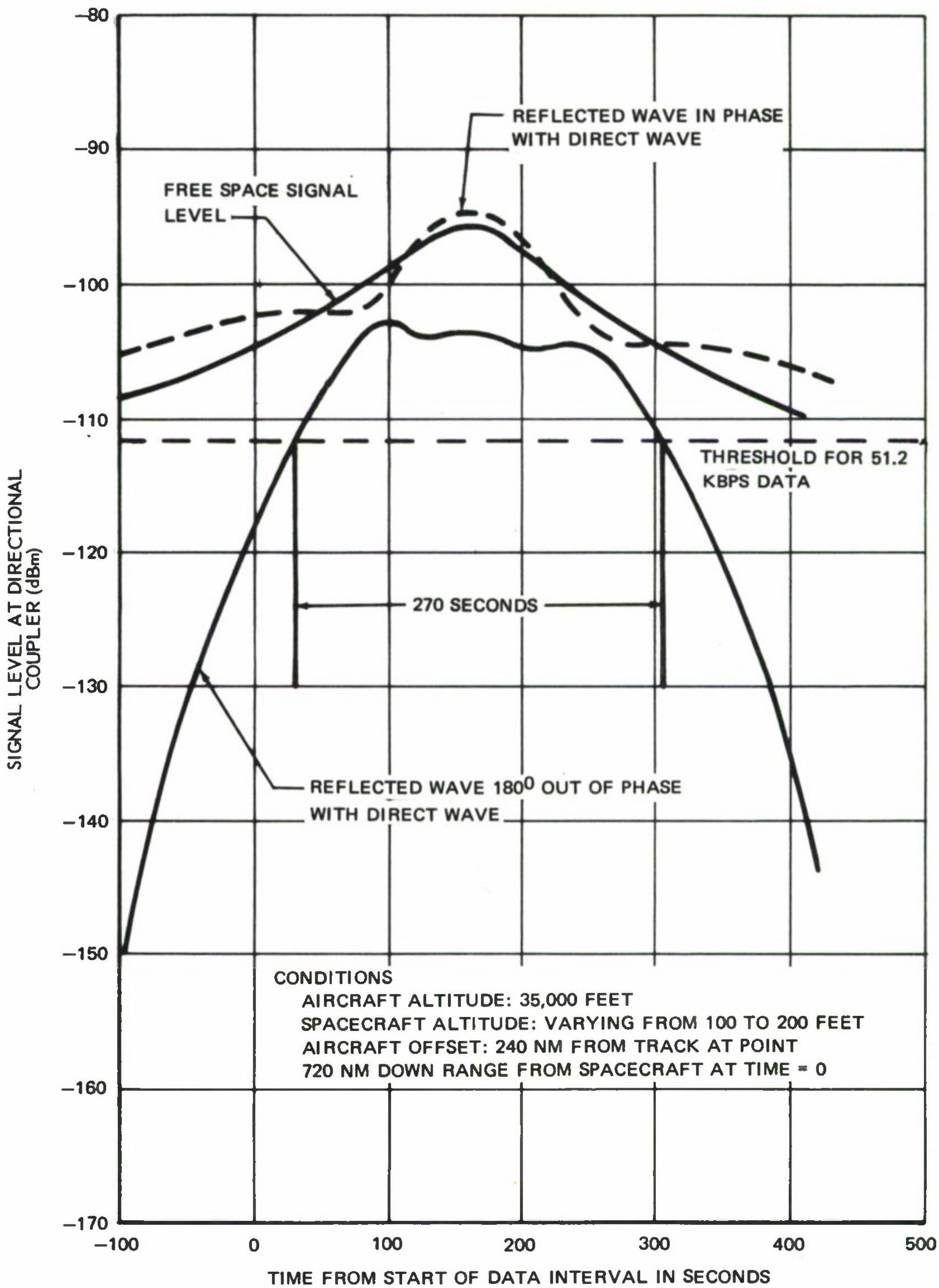


FIGURE 117. MULTIPATH EFFECTS – HORIZONTAL POLARIZATION – 20° BEAM TILT

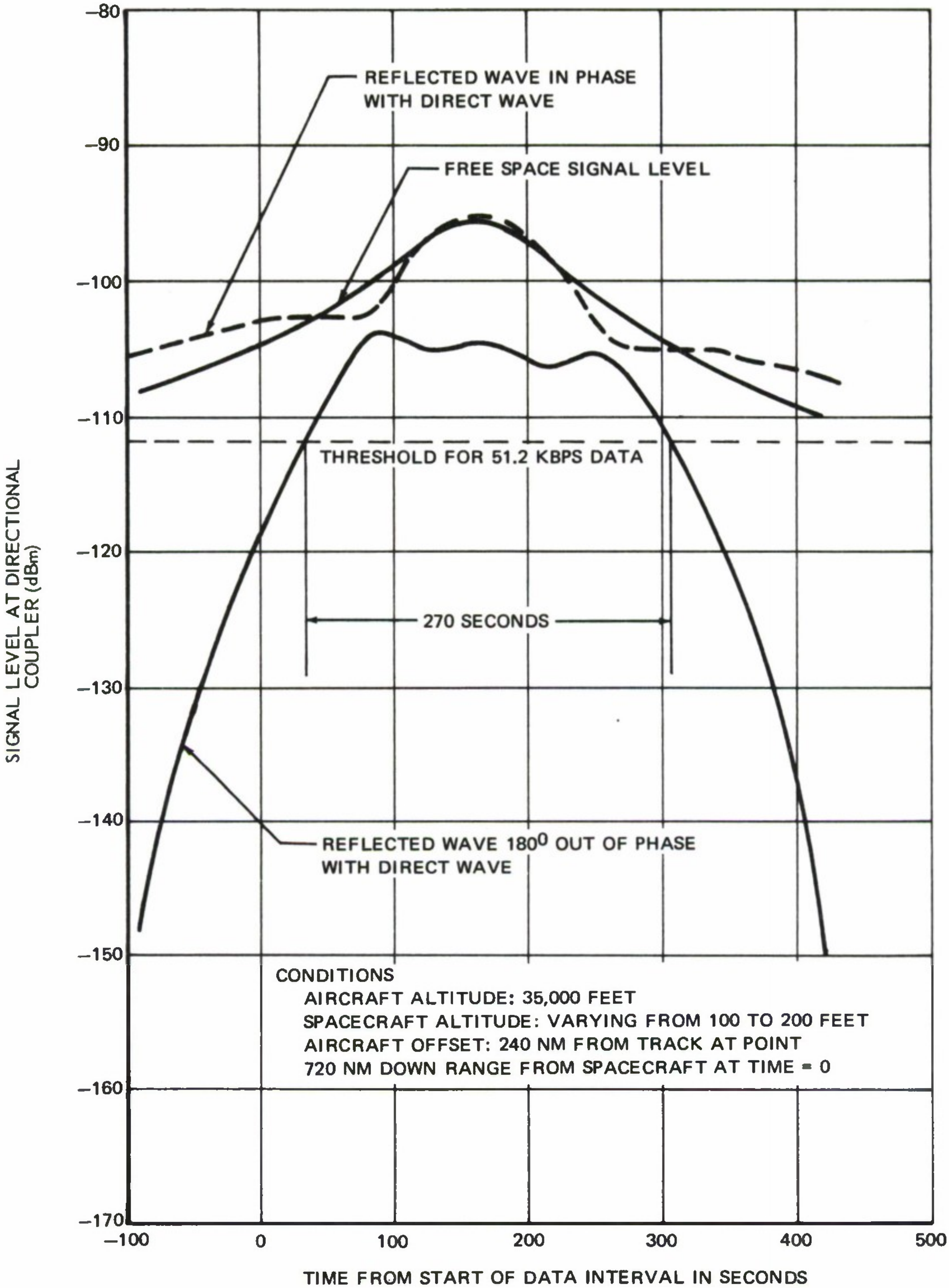


FIGURE 118. MULTIPATH EFFECTS – HORIZONTAL POLARIZATION – 23° BEAM TILT

Analysis of these curves indicates that a beam tilt of 20° maintains the signal fades above threshold for the longest period of time (270 seconds). In addition, there appears to be no advantage in varying the beam tilt angle. It is recommended that a beam tilt angle of 20° be used throughout the Apollo pass.

3.12.3.3.2 UHF

Based upon Analysis C, a data margin of +0.5 dB is predicted for Unified S-Band 51.2 KBPS data at 900 nm, while a +9.6-dB margin is indicated with 1.6 KBPS. This margin is conservative if Category II test results are considered, since a slight SNR enhancement due to coherent detection has been observed. The amount of improvement cannot be theoretically predicted, so it is not included in Analysis C. A discussion of this condition is included later in this section.

3.12.3.3.3 USB Transponder Lockup

If transponder lockup is scheduled, this should be accomplished in accordance with AS-204 Supplements to NOD, Section 61. This procedure was used several times during the flight test program and no changes are recommended.

3.12.3.3.4 Voice Relay

Analyses E and F indicate that the USB and VHF voice links have margins at 1200 nm of +9.3 dB and +5.6 dB, respectively. At the discretion of the HF operator, the downlink relay could be VHF combined, UHF combined, or VHF/UHF combined. It is recommended that the combiners be used for all downlink relays because:

a. They provide a fail-safe selection capability; if either the LHC or RHC channel fails, the combiner will select the operational channel.

b. Some SNR improvement is realized if the two channels are operational.

3.12.3.4 Analysis of Predicted A/RIA Performance Against Apollo

The Category II test results indicate that the 10-minute Apollo injection data interval can be covered by two aircraft (ref. Figures 119 and 120). Analyses A through F show that acquisition on UHF or VHF is predicted at horizon. VHF telemetry data reception will begin at 1200 nm and USB telemetry data at a minimum of 900 nm. The analyses given are conservative, and good USB data beyond 900 nm is likely. Optimum aircraft spacing is 1600 nm, with handover occurring when the spacecraft is midway between the aircraft (800 nm from each A/RIA). Figure 120 shows that the maximum slant range with this spacing is 900 nm (within the demonstrated capability of the system).

Figure 121 shows the expected output SNR of the Unified S-Band telemetry data system on an Apollo CSM pass. The output SNR is plotted against range, from 1200 nm to 200 nm. The 200 nm range is the closest approach of A/RIA to the CSM. Both curves are plotted using parameters from Analysis C. This analysis shows worst case

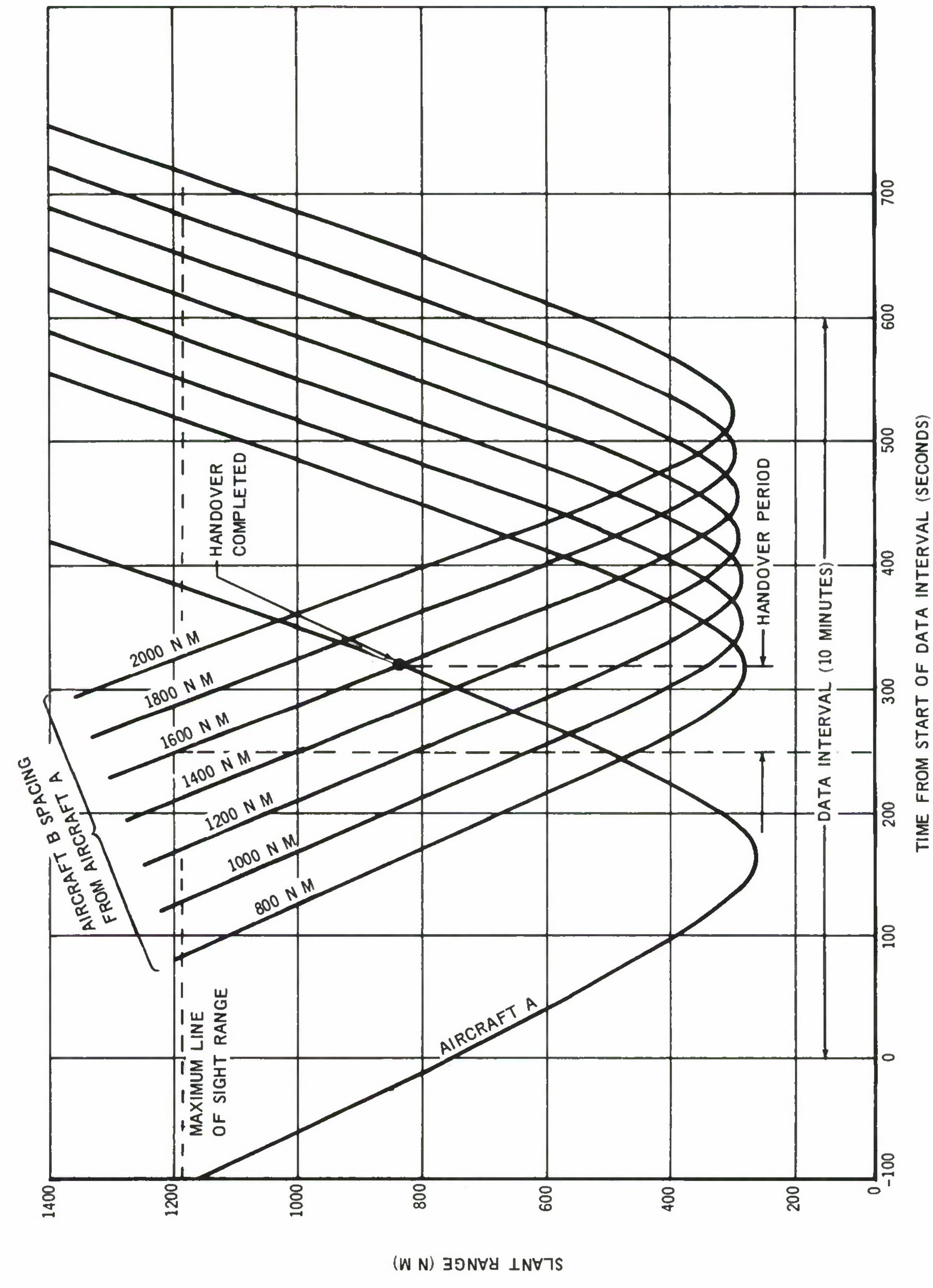
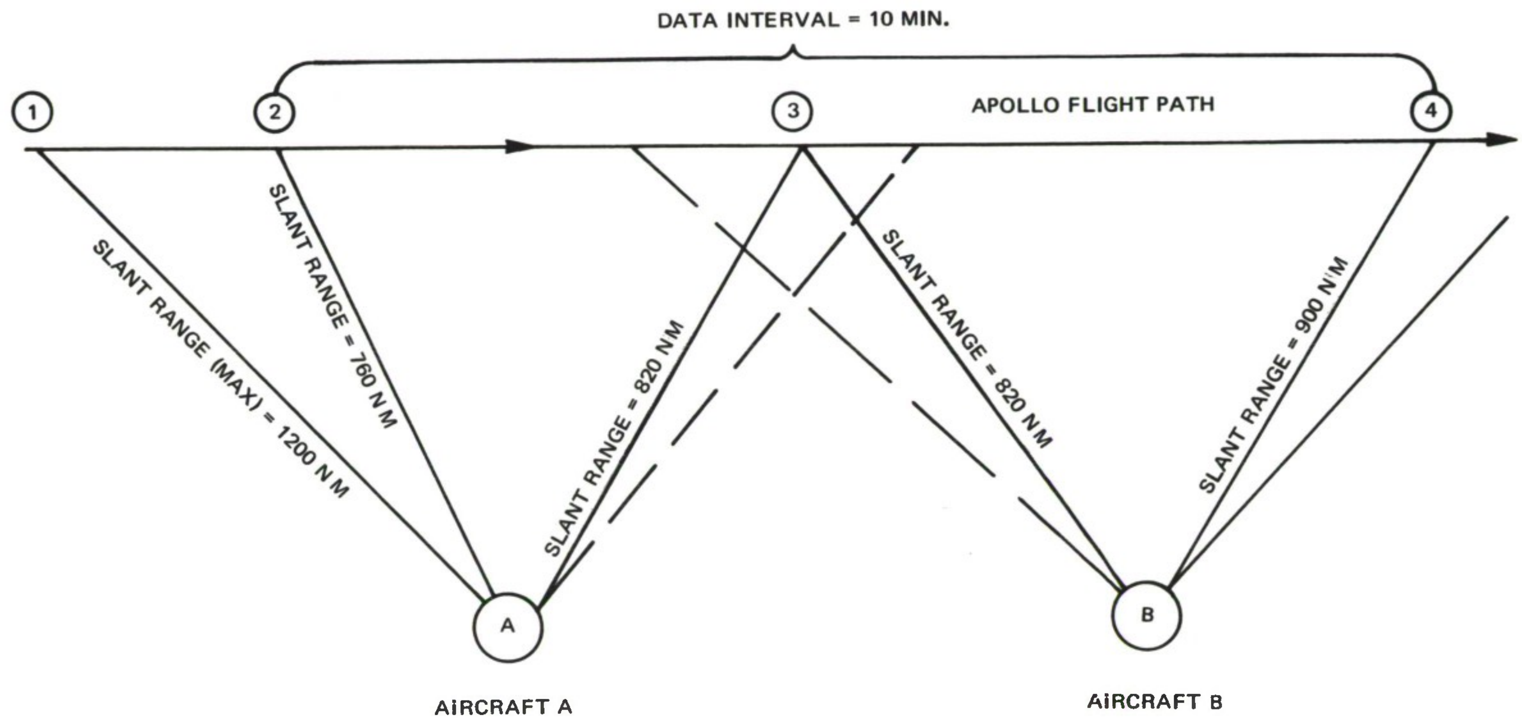


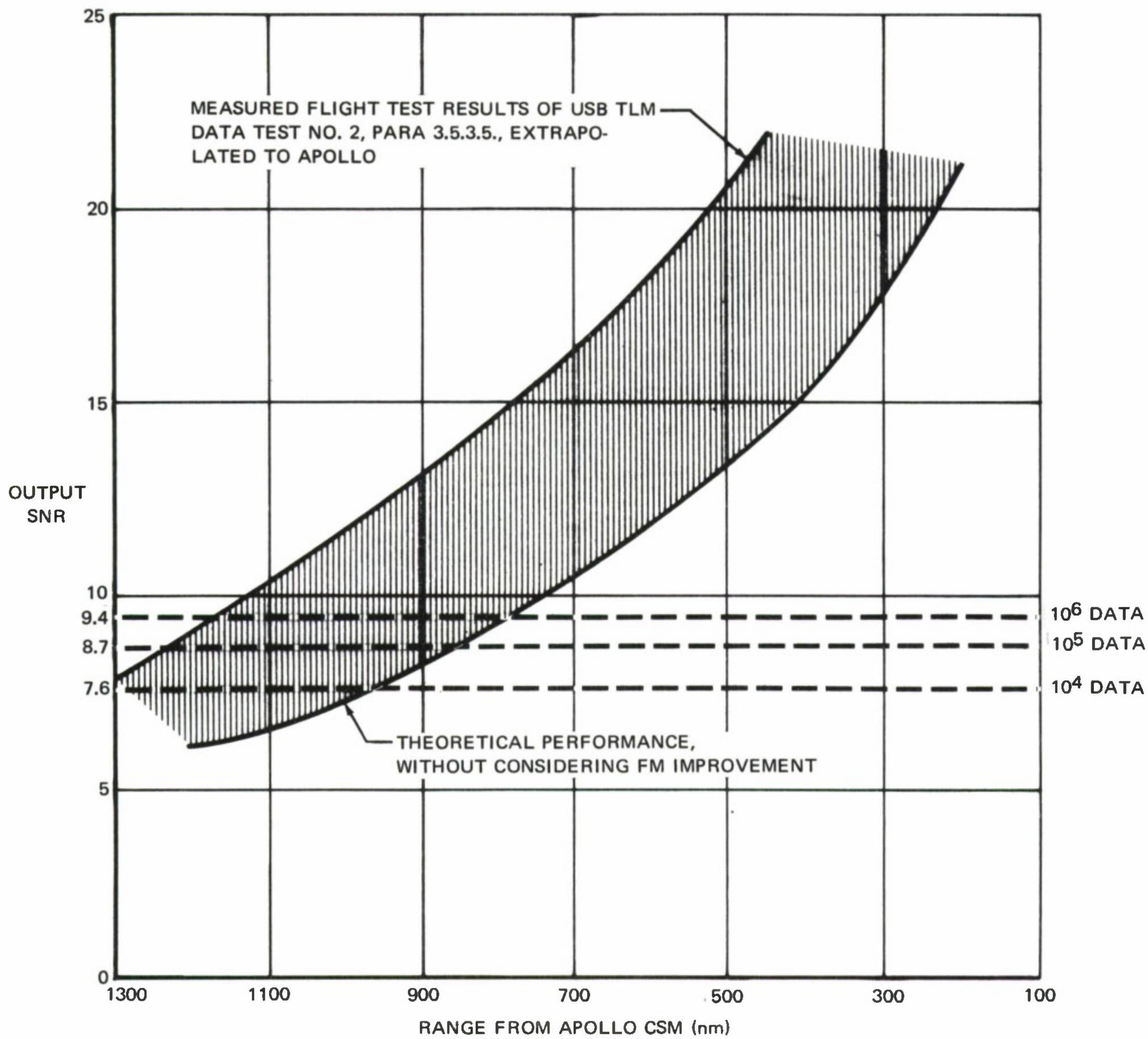
FIGURE 119. RANGE CURVES FOR APOLLO INJECTION DATA INTERVAL



SEQUENCE OF EVENTS

Aircraft A initiates antenna scan for acquisition and track at ①
From ① to ②, acquisition and lock on complete
From ② to ③, start data interval with aircraft Ⓐ in control
At ③, achieve "handover" -from aircraft Ⓐ to aircraft B
From ③ to ④, complete data interval with aircraft Ⓑ in control

FIGURE 120. DATA INTERVAL FOR APOLLO TRACK



NOTE:
BOTH CURVES ARE BASED
UPON THE LINK CALCULATION IN
ANALYSIS C

FIGURE 121. PREDICTED USB TELEMETRY DATA (51.2 KBPS) PERFORMANCE VS RANGE FROM APOLLO CSM

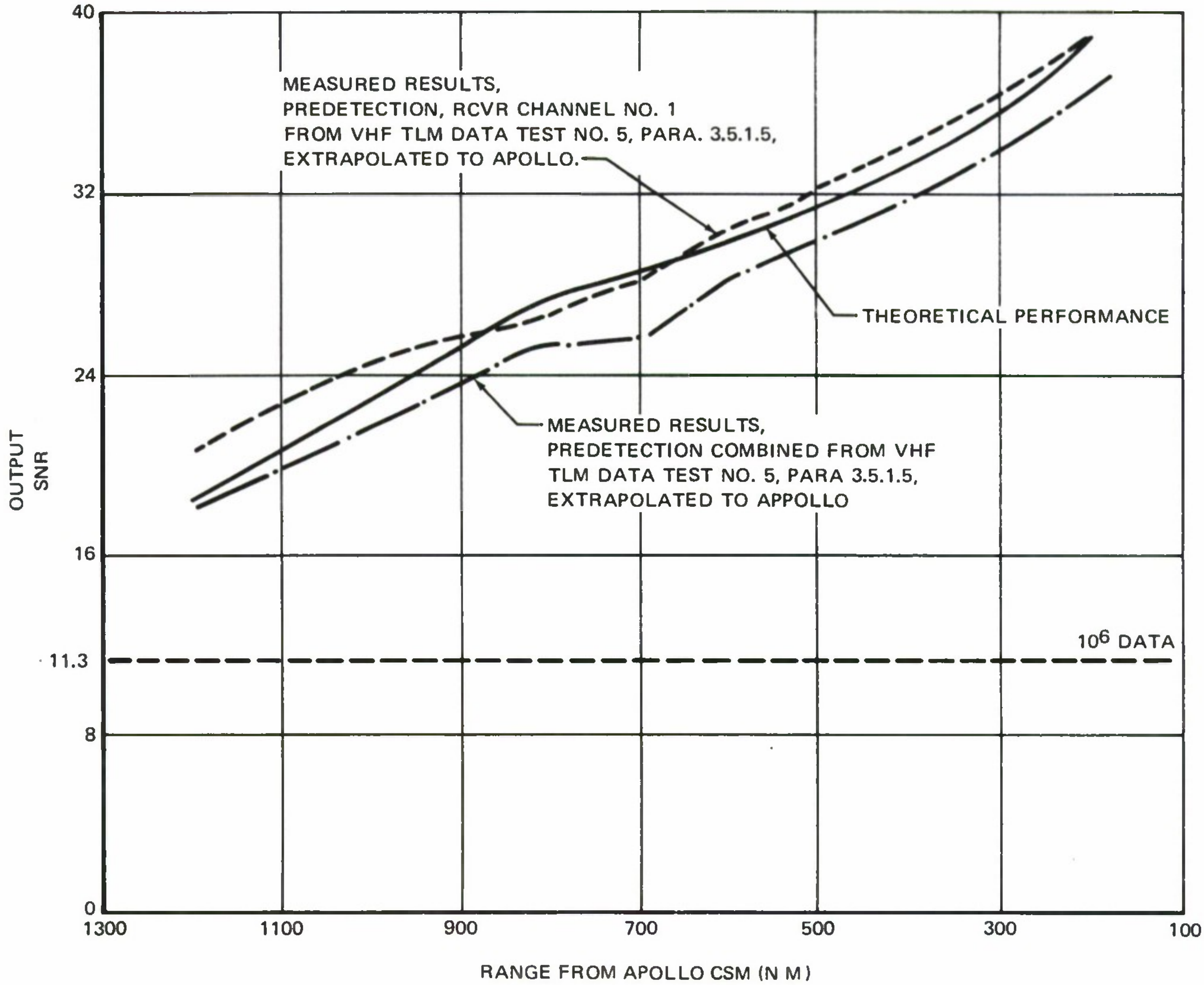
readings for all parameters. The theoretical performance curve indicates output SNR's for the 51.2-KBPS data from 6.1 dB at 1200 nm to 21.1 dB at 200 nm, with a 9.3-dB SNR (adequate for 10^6 data) occurring at approximately 800 nm. Flight test results have shown that the USB system gives an SNR improvement because of coherent detection, as indicated by the curve of measured results. The amount of improvement approaches a maximum of 6 dB. These measured results are accurate within approximately ± 2.8 dB. Using this measured results curve, the threshold of 10^6 data would move out to approximately 1150 nm.

Figure 122 is a presentation of the expected output SNR of the VHF PCM/FM telemetry data system on an Apollo CSM pass. The curves are based upon the parameters shown in Analysis D, which are derived using worst case conditions. The theoretical performance curve indicates that output SNR's for the 51.2-KBPS data range from 18.4 dB at 1200 nm to 38.5 dB at closest approach. Flight test results have shown that VHF telemetry data system performance is as predicted. In spite of the 3 to 4-dB of man-made noise present in the Tulsa area, the single channel output SNR's were consistently within approximately 2.5 dB of the theoretical, while predetection combined telemetry data SNR's were 2 to 3 dB better than the uncombined. In the quieter Apollo environment, the predetection combined data SNR would likely be above the theoretical SNR for a single channel. The figure shows that telemetry data equivalent of 10^6 quality is likely from the horizon, disregarding the effects of multipath. To extrapolate the measured test results to the Apollo environment, the difference between measured and theoretical SNR values at the various power levels were taken from Figure 59 and replotted on Figure 122. This technique was necessary because a 125-KHz video filter was used for the 51.2-KBPS data during Category II testing while a 50-KHz filter is recommended for Apollo. This wider filter resulted in a lower FM improvement and a lower IF/Video bandwidth improvement.

Two of the Saturn IVB modulation schemes were also flight tested during Category II. No range versus output SNR plots are presented because the characteristics of the Saturn IVB are unknown. The tests yielded the following results:

Telemetry Data	Frequency	Received Power	Output SNR
PCM/FM, 72 KBPS, $\pm$39 KHz deviation	232.9 MHz	5.4×10^{-13} watts/m^2	23 dB
PCM/FM, 72 KBPS, $\pm$35 KHz deviation	2287.5 MHz	2.4×10^{-14} watts/m^2	3.3 dB
		9.0×10^{-13} watts/m^2	22.5 dB

The system output SNR's were slightly better than the theoretical in all cases. These particular modulation schemes yield a negative FM improvement because of the low carrier deviation with respect to the wide IF bandwidth required by the high bit rate modulation.



NOTE:

1. ALL CURVES ARE BASED UPON THE LINK CALCULATION IN ANALYSIS D
2. MEASURED RESULTS CORRECTED FOR APOLLO CONFIGURATION POST-DETECTION BANDWIDTH OF 50 KHz
3. MEASURED RESULTS NOT CORRECTED FOR TULSA NOISE

FIGURE 122. PREDICTED VHF PCM/FM TELEMETRY DATA (51.2 KBPS) PERFORMANCE VS RANGE FROM APOLLO CSM

Analysis A - UHF acquire and track (Unified S-Band, Block II) 1200 nm acquisition, 51 KBPS or 1.6 KBPS

P_t (Transmitter Power) - - (NOTE 1)	- 41.6 dBm
L_m (Carrier Mod Loss) - - (NOTE 2)	- 4.5 dB
L_t (Xmtr Circuit Loss) - - (NOTE 3)	- 5.6 dB
G_t (Xmtr Antenna Gain) - - (NOTE 4)	- 3.0 dB
L_s (Space Loss) - - (NOTE 5)	-166.6 dB
L_a (Atmos. Atten.) - - (NOTE 6)	- 2.0 dB
L_p (Polarization Loss) - - (NOTE 7)	- 0.5 dB
Loss due to acquiring at edge of scanning beam	- 3.0 dB
L_r (Radome Loss) - - (NOTE 9)	- 0.7 dB
G_r (Receiving Ant. Gain) - - (NOTE 16)	+ 30.6 dB
P_r (Received Sig. Power)	-113.7 dBm
ΦKT (Noise Spectral Density) - - (NOTE 10)	-168.3 dBm/Hz
(C/N_1) dB, Carrier	+ 54.6 dB
Tracking Loop Noise Bandwidth (2 BLO = 2000 Hz)	- 33.0 dB
SNR required for acquisition (NOTE 11)	- 13.8 dB
Margin	+ 7.8 dB

Analysis B - VHF acquire and track (237.8 MHz, PCM/FM), 1200 nm acquisition, 51.2 KBPS or 1.6 KBPS

P_t	(Transmitter Power, 10 W., Note 17)	+ 40.0 dBm
$-L_t$	(Transmitter circuit loss, Note 18)	- 5.4 dB
G_t	(Transmitting antenna gain, Note 19)	- 3.0 dB
$-L_s$	(Space loss, 1200 nm at 237.8 MHz, Note 20)	-146.9 dB
$-L_a$	(Atmospheric Attenuation, Note 21)	- 1.0 dB
$-L_p$	(Polarization loss, Note 22)	- 3.0 dB
	(Antenna pointing loss, Note 23)	0.0 dB
$-L_R$	(Radome loss, Note 24)	- 0.3 dB
G_r	(Receiving antenna gain)	+ 13.0 dB
P_r	(Received signal power)	-106.6 dBm
Φkt	(Noise spectral density, T_{sys} = 1305°K, Note 28)	-167.4 dBm/Hz
	Predetection Noise Bandwidth (300 KHz)	- 54.8 dB
	Predetection SNR	6.0 dB
	Predetection SNR required for AUTO TRACK*	6.0 dB
	Margin	0.0 dB

*For tracking in the Apollo environment, a predetection SNR of 6 dB is not required, or recommended. This operator setting should be optimized for the particular mission to be flown. If man-made noise in the area is predicted to be low, the receiver could be adjusted to initiate autotrack at a predetection SNR of 2 to 4 dB. If noise is higher than expected, the operator can re-zero on noise and maintain a workable tracking system.

Analysis C - Unified S-Band telemetry data (Block II) at 900 nm range

	Bit Rate (KBPS)	
	51.2 KBPS	1.6 KBPS
P_t Transmitter power (Note 1)	+ 41.6 dBm	+ 41.6 dBm
L_t Transmitter ckt. Loss (Note 3)	- 5.6 dB	- 5.6 dB
G_t Transmitting Antenna Gain (Note 4)	- 3.0 dB	- 3.0 dB
L_s Space Loss (Note 5)	-164.1 dB	-164.1 dB
L_a Atmospheric Attenuation	- 2.0 dB	- 2.0 dB
L_p Polarization loss (Note 7)	- 0.5 dB	- 0.5 dB
Antenna Pointing Loss (Note 8)	- 0.6 dB	- 0.6 dB
L_r Radome Loss (Note 9)	- 0.7 dB	- 0.7 dB
G_r Receiving Antenna Gain (Note 6)	+ 30.6 dB	+ 30.6 dB
L_m TLM Subcarrier Mod. Loss (Note 2)	- 4.1 dB	- 10.1 dB
P_r Received Signal Power, TLM Subcarrier	-108.4 dBm	-114.4 dBm
ΦKT Noise Spectral Density (Note 10)	-168.3 dBm/Hz	-168.3 dBm/Hz
Predetection noise bandwidth	+ 51.8 dB	+ 37.8 dB
(150 KHz at 51.2 KBPS, 6 KHz at 1.6 KBPS)		
Predetection SNR	+ 8.1 dB	+ 16.1 dB
IF/VIDEO Bandwidth Improvement		
10 log B -10 log 2b (b = 75 KHz, 3 KHz)		
Output SNR	+ 8.1 dB	+ 16.1 dB
SNR Req'd for BER of 10^{-4} (Note 15)	+ 7.6 dB	+ 6.5 dB
Margin	+ 0.5 dB	+ 9.6 dB

Analysis D - VHF PCM (FM telemetry data) at 1200 nm range

		Bit Rate (KBPS)	
		51.2 KBPS	1.6 KBPS
P_t	Transmitter power, 10 W (Note 17)	+ 40.0 dBm	+ 40.0 dBm
$-L_t$	Transmitter ckt. loss (Note 18)	- 5.4 dB	- 5.4 dB
G_t	Transmitting Antenna Gain (Note 19)	- 3.0 dB	- 3.0 dB
$-L_s$	Space loss, 1200 nm at 237.8 MHz (Note 20)	-146.9 dB	-146.9 dB
$-L_a$	Atmospheric Attenuation (Note 21)	- 1.0 dB	- 1.0 dB
$-L_p$	Polarization loss (Note 22)	- 3.0 dB	- 3.0 dB
$-L_r$	Radome loss (Note 24)	- 0.3 dB	- 0.3 dB
G_r	Receiving Antenna Gain	+ 13.0 dB	+ 13.0 dB
P_r	Received signal power	-106.6 dBm	-106.6 dBm
ΦKT	Noise spectral density (TSYS = 1305°K)	-167.4 dBm/Hz	-167.4 dBm/Hz
	Predetection noise bandwidth (300 KHz)	+ 54.8 dB	+ 54.8 dB
	Predetection SNR	+ 6.0 dB	+ 6.0 dB
	IF/Video bandwidth improvement 10 log B -10 log 2b, where B = 300 KHz, b = 50 KHz or 3 KHz	+ 4.8 dB	+ 17.0 dB
	FM improvement $10 \log \left[3 \left(\frac{\Delta f}{b}\right)^2\right]$ (Note 29)	+ 12.7 dB	+ 37.2 dB
	Threshold loss (Note 30)	- 5.1 dB	- 14.9 dB
	Output SNR	+ 18.4 dB	+ 45.1 dB
	SNR required for BER of 10^{-6} (Note 31)	+ 11.3 dB	+ 8.3 dB
	Margin	+ 7.1 dB	+ 36.8 dB

Analysis E - Unified S-Band voice (Block II) at 1200 nm range

		Bit Rate (KBPS)	
		51.2 KBPS	1.6 KBPS
P_t	Transmitter Power (Note 1)	+ 41.6 dBm	+ 41.6 dBm
L_t	Transmitter ckt. loss (Note 3)	- 5.6 dB	- 5.6 dB
G_t	Transmitting Antenna Gain (Note 4)	- 3.0 dB	- 3.0 dB
L_s	Space Loss (Note 5)	-166.6 dB	-166.6 dB
L_a	Atmospheric Attenuation	- 2.0 dB	- 2.0 dB
L_p	Polarization loss (Note 7)	- 0.5 dB	- 0.5 dB
	Antenna Pointing Loss (Note 8)	- 0.6 dB	- 0.6 dB
L_r	Radome loss (Note 9)	- 0.7 dB	- 0.7 dB
G_r	Receiving Antenna Gain (Note 16)	+ 30.6 dB	+ 30.6 dB
L_m	Voice Subcarrier Mod. Loss (Note 2)	- 10.1 dB	- 4.1 dB
P_r	Received Signal Power, Voice Subcarrier	-116.9 dBm	-110.9 dBm
ΦKT	Noise Spectral Density (Note 10)	-168.3 dBm/Hz	-168.3 dBm/Hz
	Predetection noise bandwidth $2\ BL_o = 20$ KHz	+ 43.0 dB	+ 43.0 dB
	Predetection SNR	+ 8.4 dB	+ 14.4 dB
	IF/Audio Bandwidth Improvement $10 \log B - 10 \log 2b$ ($b = 3$KHz)	+ 5.2 dB	+ 5.2 dB
	FM Improvement $10 \log \left[3 \left(\frac{\Delta f}{b}\right)^2\right]$	+ 12.7 dB	+ 12.7 dB
	Threshold loss (Note 13)	- 2.0 dB	+ 0.0 dB
	Output SNR	+ 24.3 dB	+ 32.3 dB
	Desired SNR	+ 15.0 dB	+ 15.0 dB
	Margin	+ 9.3 dB	+ 17.3 dB

Analysis F - VHF AM voice (296.8 MHz)

P_t	Transmitter power, 10 W (Note 17)	+ 37.0 dBm
L_t	Transmitter ckt. loss (Note 18)	- 3.0 dB
G_t	Transmitting Antenna Gain (Note 19)	- 3.0 dB
L_s	Space loss, 1200 nm at 296.8 MHz (Note 20)	-148.8 dB
L_a	Atmospheric Attenuation (Note 21)	- 1.0 dB
L_p	Polarization loss (Note 22)	- 3.0 dB
L_r	Radome loss (Note 24)	- 0.3 dB
G_r	Receiving Antenna gain	+ 13.0 dB
P_r	Received signal power	-109.1 dBm
ΦKT	Noise spectral density (TSYS = $1300^{\circ}K$)	-167.5 dBm/Hz
	Predetection noise bandwidth (30 KHz)	44.8 dB
	Predetection SNR	+ 13.6 dB
	Required SNR for AM demod threshold	+ 5.0 dB
	Acquisition Margin	+ 8.6 dB

<u>Calculation of Output SNR</u>

Predetection SNR	+ 13.6 dB
IF/Audio bandwidth improvement 10 log B - 10 log 2 b, where (b = 3 KHz)	+ 7.0 dB
Mod loss = 20 m, where m = 1.0	0.0 dB
Output SNR	+ 20.6 dB
Desired output SNR	+ 15.0 dB
Margin	+ 5.6 dB

NOTE 1

In accordance with References 2 and 3, the CSM transmitter power levels assumed are:

High Power:	14.4 W (+ 11.6 dBW)
Low Power:	2.9 W (+4.6 dBW)

NOTE 2

MODULATION LOSS CALCULATIONS

The PM indices for modulation of the Unified S-band carrier by the voice and telemetry subcarriers as specified in Reference 1 for Block II CSM equipment is tabulated below:

TM Data Rate	Subcarrier	Phase Modulation Index (Radians Peak) Block II
51.2 KBPS	Voice, 1.25 MHz	0.7
	TM, 1.024 MHz	1.2
1.6 KBPS	Voice, 1.25 MHz	1.2
	TM, 1.024 MHz	0.7

Modulation loss calculations for Block II-51.2 KBPS/1.6 KBPS rates.

a. Block II - 51.2 KBPS Data Rate

Carrier = -4.5 dB

Voice Subcarrier = -10.1 dB

Telemetry Subcarrier = -4.1 dB

b. Block II - 1.6 KBPS Data Rate

Carrier = -4.5 dB

Voice Subcarrier = -4.1 dB

Telemetry Subcarrier = -10.1 dB

NOTE 3

Based on Reference 4, the assumed CSM transmitter circuit loss is 5.6 dB.

NOTE 4

Gain of the CSM omni-directional antenna is assumed to be -3 dB per References 4 and 5.

NOTE 5

$$L_s = 37.8 + 20 \log f_{mc} + 20 \log R$$

where

f_{mc} = frequency in megacycles = 2287.5 MHz

R = slant range in nautical miles

The maximum calculated radio line-of-sight range for a spacecraft altitude of 100 nm and an aircraft altitude of 35,000 feet is 1190 mn ($\approx$ 1200 nm)

NOTE 6

One-way atmospheric attenuation due to oxygen and water vapor at 2300 MHz and zero elevation angle per Figure 7, page 83 of Reference 6. In this analysis, a zero elevation angle represents the specified or worst case condition, with a corresponding attenuation of 2 dB.

NOTE 7

Polarization Loss (Specified or worst case)

The polarization power loss factor is given by:

$$K_p = 1/2 \quad 1 \quad \frac{\pm 4 A_T A_R + (1-A_T^2)(1-A_R^2) \cos 20\,\alpha}{(1 + A_T^2) \quad (1 + A_R^2)}$$

where: A_T = voltage ratio of minor to major axis for receiving antenna polarization ellipse

A_R = voltage ratio of minor to major axis for receiving antenna polarization ellipse

α = angle between major axes of polarization ellipses

(+) sign is used for same sense of rotation

(-) sign is used for opposite sense of rotation

For the case of a linear spacecraft polarization and a circular aircraft polarization of 2 dB ellipticity,

A_T = 0

A_R = 0.794 (from 20 log A_R = -2 dB)

Assuming for worst case conditions that = 90°,

$$K_p = 0.5 \left\{ \frac{1 + [1 - (0)^2][1 - (0.794)^2] \quad (-1)}{[1 + (0)^2][1 + (0.794)]} \right. = 0.387$$

Power loss in dB = 10 log 0.387 = -4.1 dB (specified or worst case value)

For the case of a circular spacecraft polarization of 4 dB ellipticity and a circular aircraft polarization of 2 dB ellipticity,

A_T = 0.630 (from 20 log A_T = -4 dB)

A_R = 0.794 (from 20 log A_R = -2 dB)

Again assuming for worst case conditions that = 90°, cos = cos 180° = -1,

$$K_p = 0.5 \left\{ 1 + \frac{+4 \times 0.630 \times 0.794 + [1 - (0.630)^2] \; [1 - (0.794)^2] \; (-1)}{1 + (0.630)^2 \qquad\qquad 1 + (0.794)^2} \right. = 0.890$$

Power loss in dB = 10 log 0.890 = -0.5 dB

NOTE 8

a. Antenna Pointing Loss

Antenna pointing loss is based on a tracking error of 1°:

$$\text{Loss} = 12\left(\frac{1}{4.5}\right) = 12 \times 0.0495 = 0.6 \text{ dB}$$

b. Scanning Beam Loss

During acquisition scanning of the antenna beam, the diameter of the beam is taken as the 3 dB down point. Therefore, a 3 dB loss is assumed.

NOTE 9

a. Radome loss - Specified

In accordance with A/RIA Specification No. CP 100009A, Paragraph 3.1.1.1.1.2.1, the one-way power transmission efficiency of the radome shall not be less than 90 percent average and 85 percent minimum. Using the minimum condition (85 percent).

$$\text{Power loss in dB} = 10 \log\left(1 \frac{-0.15}{1}\right) = \underline{0.7 \text{ dB}}$$

NOTE 10

The measured noise figure on the first three A/RIA aircraft were as follows:

UHF	Sum Channel		Difference Channel	
	RHC	LHC	RHC	LHC
A/RIA 372	5.0 dB	5.8 dB	8.0 dB	8.4 dB
A/RIA 375	5.0 dB		8.0 dB	8.3 dB
A/RIA 330	6.0 dB	6.7 dB	7.0 dB	7.0 dB

The worst case reading of 6.7 dB (A/RIA 330, LHC) = 1069°K will be used for UHF.
Φ KT = -198.3 dBW/Hz (-168.3 dBm/Hz)

NOTE 11

Test results of Unified S-Band aequisition threshold test (Paragraph 3.4.2.5, Test 4) show that the threshold is -119 dBm at the A/RIA direetional eoupler, or -117 dBm at the antenna load for a modulated earrier with automatie aequisition. For an unmodulated earrier, aequisition oeeurs at -121.5 dBm. The SNR required for acquisition thus beeomes:

Noise Speetral Density	-168.3 dBm
Pre-D Noise Bandwidth	33.0 dB
	135.3 dBm
Aequisition Threshold	121.5 dBm
SNR Required for acquisition	13.8 dB

NOTE 12

Peak FM deviation on subearrier = 7.5 KHz per page 36 of reference 1.

$$\text{FM improvement} = 10 \log \; 3 \left(\frac{\Delta f}{b}\right)^2$$

$$= 10 \log \; 3 \left(\frac{7.5}{3}\right)^2 = 12.7 \text{ dB}$$

NOTE 13

Caleulated in dB as 1.2 (10 - Predeteetion SNR)

NOTE 14

The 1.024 MHz subcarrier is biphase modulated with a $\frac{\pi}{2}$ or 1.57 radians. Since this peak phase excursion swings to the maximum of the phase detector sine wave response, the assumption of a linear detector response is invalid. The voltage response is reduced from the linear value for a given $\Delta\theta$ by the factor $\sin\frac{\Delta\theta}{\Delta\theta}$

For $\Delta\theta = \frac{\pi}{2}$, this factor is $\frac{1}{\pi/2} = \frac{1}{1.57}$

Thus, the biphase modulation with $\Delta\theta = 1.57$, gives a peak response equivalent to that for a $\Delta\theta' = \frac{1.57}{1.57} = 1$ radian peak swing for a linear detection characteristic. The rms value of this is $\frac{1}{\sqrt{2}} = 0.707$. By equation (16-7) of Reference 8, the rms loop noise phase error in radians is given by

$$\sigma^2 = \frac{0.5}{(S/N)_B}$$

where $(S/N)_B$ = predetection SNR is predetection bandwidth B.

Taking into account the predetection to post-detection bandwidth improvement factor, the output SNR is given by

$$(S/N)_o = \frac{(0.707)^2}{\frac{0.5}{(S/N)_B}} \cdot \frac{B}{2b} = \frac{B}{2b} \cdot (S/N)_B = \frac{S}{N_1} \cdot \frac{1}{2b}$$

Where b = postdetection bandwidth

In decibel form,

$$(S/N)_o \text{ dB} = 10 \log (S/N)_o = 10 \log (S/N_1) - 10 \log 2b$$
$$= (S/N_1)_{dB} - 10 \log 2b$$

NOTE 15

The bit error probability is a function of the normalized SNR, E/N_o, where

E = average signal energy per bit

N_o = noise power density

The average SNR, S/N, is related to the normalized SNR by the equation:

$$S/N = \frac{E/T_o}{N_{ob}} = E/N_o \; , \; 1/T_{ob}$$

where

T_o = bit duration

b = post-detection bandwidth

Since $1/T_o$ = bit frequency = f_b

$S/N = E/N_o \; fB/B$

In decibel form

$$S/N_{dB} = (E/N_o)_{dB} + 10 \log f_B/b$$

From Figure 10 of Reference 9, the required value of $(E/N_o)_{dB}$ for a bit error probability of 10^{-4} in a differentially coherent PSK system is 9.2 dB. Then:

$$(S/N)_{dB} = 9.2 + 10 \log f_B/b$$

For the bit frequency of 51.2 KBPS, b = 75 KHz, and

$$(S/N)_{dB} = 9.2 = 10 \log 51.2/75 = 9.2 + 10 \log 0.683 = 7.6 \text{ dB}$$

For the bit frequency of 1.6 KBPS, b = 3 KHz, and

$$(S/N)_{dB} = 9.2 + 10 \log 1.6/3 = 9.2 + 10 \log 0.533 = 6.5 \text{ dB}$$

If a bit error probability of 10^{-6} is desired, the value of $(E/N_o)_{dB}$ is 11 dB (Figure 10 of Reference 9), instead of 9.2 dB. The above values of $(S/N)_{dB}$ must then be increased by 11 - 9.2 = 1.8 dB giving:

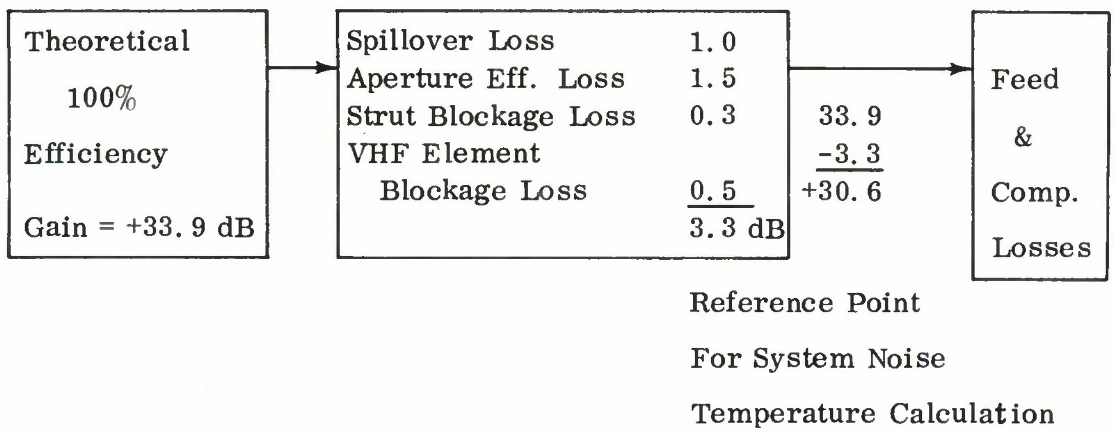
$$(S/N)_{dB} = 7.6 + 1.8 = \underline{+9.4 \text{ dB for } 51.2 \text{ KBPS}}$$

$$= 6.5 + 1.8 = \underline{+8.3 \text{ dB for } 1.6 \text{ KBPS}}$$

NOTE 16

Reference Point and Antenna Gain for UHF System Noise Temperature Calculation

The reference point for the system noise calculations is taken at the antenna proper, ahead of the ohmic losses associated with feed components. For signal-to-noise calculations, the antenna gain should be referenced at the same point and it is therefore important to determine the antenna gain value applicable at this point. The theoretical gain at 100 percent efficiency for the antenna is +33.9 dB. The losses that must be reflected to obtain the gain value at the reference point for system noise temperature are given below:



The reference point for measuring antenna gain is at the output of the comparator where the following gain values apply:

$$\begin{array}{r} +30.6 \\ \underline{-\ 1.6} \\ +29.0 \end{array}$$

NOTE 17

Transmitter power per Reference 4.

NOTE 18

Transmitter circuit loss per Reference 4.

NOTE 19

Gain of the CSM omni-directional antenna is assumed to be -3 dB per References 1 and 4.

NOTE 20

$$L_s = 37.8 + 20 \log f_{MHz} + 20 \log R$$

where f_{MHz} = frequency in megahertz

R = slant range in nautical miles

The maximum calculated radio line-of-sight range for a spacecraft altitude of 100 nm and on aircraft altitude of 35,000 feet is 1190 nm $\approx$ 1200 nm.

NOTE 21

One-way atmospheric attenuation due to oxygen and water vapor at VHF and zero elevation angle per Figure 7, page 83 of Reference 6.

NOTE 22

Spacecraft VHF antenna polarizations is linear per References 1 and 4.

Polarization loss is based on:

Linear spacecraft to circular aircraft:	-3 dB
or	
Linear spacecraft to linear aircraft with 45^{o} misalignment:	-3 dB

NOTE 23

Antenna pointing loss is based on a tracking error of 1^{o}:

$$\text{Loss} = 12\ (1/40)^2 = 0.0075 \text{ dB}$$

NOTE 24

Reference 7 states that radome power loss at VHF is 0.5 percent plus 4 percent loss caused by lightning strips and 2 percent for coating. Total loss is then 0.5 + 4 + 2 = 6.5 percent.

$$\text{Power loss in dB} = 10 \log \frac{1 - 0.065}{1} = -0.3 \text{ dB}$$

NOTE 25

Receiving System noise temperature per A/RIA Technical Note A0140. The noise temperature of the VHF voice channel was not measured during Category II tests.

NOTE 26

This value may be degraded at low elevation angles by man-made noise. During Category II, for flights near Tulsa, the noise level increased by approximately 4 dB at VHF frequencies when the antenna was pointed down (0 dB referenced to antenna at zenith). The man-made noise effect would depend upon what area on the earth was seen by the antenna.

NOTE 27

Block II CSM modulation is 100 percent per Reference 1.

NOTE 28

The measured noise figures for the first three A/RIA aircraft were as follows:

	Sum Channel		Difference Channel	
VHF	RHC	LHC	RHC	LHC
A/RIA 372	6.8 dB	6.4 dB	7.0 dB	6.1 dB
A/RIA 375	7.4 dB	7.3 dB	6.8 dB	7.3 dB
A/RIA 330	6.8 dB	5.8 dB	6.3 dB	5.8 dB

The worst case reading of A/RIA 375, RHC = 1305°K will be used. VHF Φ KT = 197.4 dBW/Hz

$$10 \log (1.38 \times 10^{-23} \times 1305^{\circ}K) = -197.3 \text{ dBW/Hz} \quad (-167.3 \text{ dBm/Hz})$$

NOTE 29

$$\text{FM Improvement} = 10 \log \left[3 \left(\frac{\Delta f}{b} \right)^2 \right]$$

$$= 10 \log \left[3 \left(\frac{125}{50} \right)^2 \right] = 12.7 \text{ dB (51.2 KBPS)}$$

$$= 10 \log \left[3 \left(\frac{125}{3} \right)^2 \right] = 37.2 \text{ dB (1.6 KBPS)}$$

NOTE 30

Calculated in dB:

For 51.2 KBPS: 1.27 (10 - Predetection SNR) = 5.1 dB

For 1.6 KBPS: 3.72 (10 - Predetection SNR) = 14.9 dB

NOTE 31

(Derived from TN A0141B Note 14)

The bit error probability is a function of the normalized SNR, E/No, where

E = average signal energy per bit

N_o = noise power density

The average SNR, S/N, is related to the normalized SNR by the equation -

$$S/N = \frac{E/T_o}{bN_o} = \frac{E}{N_o} \cdot \frac{1}{b\,T_o}$$

where T_o = bit duration

b = post-detection bandwidth

Since $1/T_o$ = bit frequency = f_B

$$S/N = E/N_o \cdot f_B/b$$

In decibel form

$$(S/N)_{dB} = (E/N_o)_{dB} + 10 \log f_B/b$$

From Figure 10 of Reference 9, the required value of $E/N_{o\,dB})$ for a bit error probability of 10^{-6} in a non-coherent FSK system is 11.0 dB and for a bit error probability of 10^{-4} it is 9.2 dB.

Then $(S/N)dB_1 = 11.0 \text{ dB} + 10 \log f_B/b \ (BER = 10^{-6})$

$(S/N)dB_2 = 9.2 \text{ dB} + 10 \log f_B/b \ (BER = 10^{-4})$

For f_B = 51.2 KBPS, b = 100 KHz

$(S/N)dB_1 = 11.0 \text{ dB} + 10 \log 51.2/100$

$= 11.0 \text{ dB} + 10 \log 0.512 = 11.0 \text{ dB} - 2.9 \text{ dB} = 8.1 \text{ dB} \ (10^{-6})$

$(S/N)dB_2 = 9.2 + 10 \log 0.512 = 9.2 - 2.9 \text{ dB} = 6.3 \text{ dB} \ (10^{-4})$

For f_B = 1.6 KBPS, b = 3 KHz

$(S/N)dB_1 = 11.0 \text{ dB} + 10 \log 1.6/3$

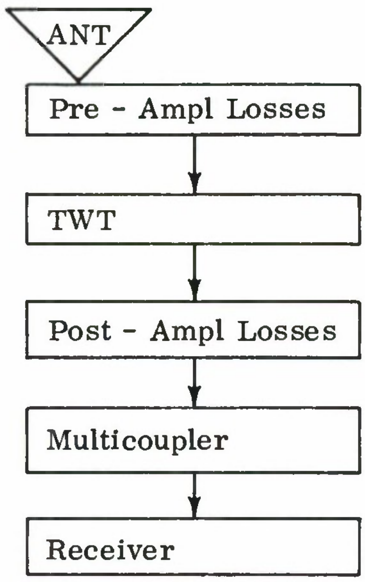
$= 11.0 \text{ dB} + 10 \log 0.534 = 11.0 \text{ dB} - 2.7 \text{ dB} - 8.3 \text{ dB} \ (10^{-6})$

$(S/N)dB_2 = 9.2 + 10 \log 0.534 = 9.2 \text{ dB} - 2.7 \text{ dB} = 6.5 \text{ dB} \ (10^{-4})$

NOTE 32

System Noise Temperature Calculation

Wide band (1435-2300 MHz)



Sum Channel

$T_A = 103^{o}K$

$L_1 = 6.6$ dB (4.57)
$T_1 = 1035^{o}K$

$G_1 = 20$dB (100)
$NF_1 = 4.5$dB, $T_2 = 527^{o}K$

$L_2 = 6.0$dB (4.0)
$T_3 = 870^{o}K$

$G_2 = 2$dB (0.63)
$NF_2 = 14.5$dB, $T_4 = 7883^{o}K$

$NF_3 = 12.0$dB, $T_5 = 4300^{o}K$

$$T_{SYS} = T_A + T_1 + L_1T_2 + \frac{L_1T_3}{G_1} + \frac{L_1L_2T_4}{G_1} \quad \frac{L_1L_2T_5}{G_1G_2}$$

$$T_{SYS} = 103^{o} + 1035^{o} + 2410^{o} + 39.7^{o} + 1440^{o} + 1248^{o} = 6276^{o}K$$

Noise Spectral Density = 10LOG $(1.38 \times 10^{-23} \times 6276)$ = -190.6dBW/Hz
This equates to -160.6dBm/Hz

<u>Expected Improvement = 3dB</u>

Therefore expected Noise Spectral Density = -163.6dBm/Hz

REFERENCES

1. Command and Service Module - Manned Space Flight Network Signal Performance and Interface Specification, Block II, North American Aviation, Inc. Document No. SID 64-1613, revised 22 February 1965.

2. Ground Operational Support System Interface Report, Section I, The Apollo Spacecraft, North American Aviation, Inc. Document No. SID 64-1613, revised 22 February 1965.

3. S-Band Power Amplifier Equipment, North American Aviation, Inc. Specification MC 478-0020A, Amendment I dated 29 July 1963.

4. Letter from ESD (Lt. Colonel Lawrence M. Politzer) to Douglas Aircraft Company, Inc. (Attention Mr. E. M. Barnes) dated 1 March 1966.

5. S-Band Circuit Margin ICD, Block II, North American Aviation, Inc. Document MHol-13001-414, dated 30 July 1965.

6. The Effective Noise Temperature of the Sky by David C. Hogg and W. W. Mumford, Microwave Journal, March 1960.

7. TWX-D26-DEO-66-27 from Douglas Aircraft Co., Inc. to Bendix Radio (V. R. Hunt) dated 23 March 1966.

8. The Pioneer IV Lunar Probe: a minimum power FM/PM System Design by D. B. Martin, Jet Propulsion Laboratory, Technical Report No. 32-215, dated March 15, 1962.

9. Comparison of PSK vs FSK and PSK vs FSK-AM Binary Coded Transmission Systems by A. B. Glenn, I.R.E. Transactions on Communications Systems, Vol. GS-8, June 1960.

3.12.4 Aircraft Operations

3.12.4.1 Summary of Operations

Three missions were flown in the actual operational environment during Category II (two with Gemini XII and one with a DOD ballistic missile). The predicted performance parameters were used for aircraft operational planning together with the emperical knowledge gained during the testing period. No problems were encountered with A/RIA availability, or meeting specific requirements of the mission profiles. All three missions were successful from the operational standpoint.

3.12.4.2 Gemini Mission

3.12.4.2.1 Coordination

The A/RIA engineering tests were scheduled with Gemini XII (NCG 628) on a non-interference basis. These tests, which were not a contractual obligation, were coordinated by the Contractor through ESD with NASA GSFC and MSC. Because of time restrictions, teletype messages between the participating agencies and the Contractor were used as mission directives in lieu of an official Operational Directive (OD).

The A/RIA was directed to fly in the vicinity of the Texas station to receive and record VHF telemetry and spacecraft voice as well as relaying spacecraft voice to GSFC during Orbits 13, 14, 15, 43, 44, and 45. During a designated pass over Texas the A/RIA was to be used as a live air-to-ground remoting station in lieu of TEX. The aircraft was not to go remote, unless positive communications were maintained with Houston Comm Tech. Updated pointing data was to be passed to the A/RIA via the HF net to the PMEE HF operator, and via VHF to the Flight Crew. Representatives of the concerned agencies were to be on-site at Tulsa one day before the first scheduled A/RIA mission.

The planned Gemini flight profile had placed the spacecraft in a high apogee orbit ($\approx$ 400 nm) during the A/RIA revolutions of interest. However, this flight profile was not achieved, and the spacecraft remained at approximately 120 nm altitude, necessitating real-time changes in pointing data and acquisition times.

3.12.4.2.2 Operational Planning

The basic requirements for A/RIA deployment are shown below:

a. The aircraft positioned south of Houston over the Gulf of Mexico.

b. Each OSP to be off-set the spacecraft ground track by 250 to 300 nm.

c. Mission duration of approximately 7 hours.

The perpendicular and the button-hook approaches to the spacecraft ground track were to be evaluated.

3.12.4.2.3 A/RIA Mission

The gross weight at take-off for both flights was approximately 240,000 pounds with a cg of 26.1 percent MAC. The flight personnel are shown in Table LIII. The general mission procedure was the same for both flights with a detailed operational sequence shown in Table LIV. The selected OSP's were satisfactory for the first flight where the points-of-closest-approach (PCA) were approximately 160, 210, and 260 nm for orbits 13 through 15 respectively. No operational problems were encountered on this flight. Figure 123 is a geometrical presentation of the relative aircraft-spacecraft positions during Orbits 13 and 15.

The OSP's selected for Orbits 43 through 45 were in error and the aircraft was very nearly on the spacecraft ground track. On Orbit 43, the fast angular rate was not anticipated and the signal was lost when the UHF/VHF antenna drove into the azimuth limits. The aircraft turn-rate was increased for Orbit 44, and autotrack was maintained throughout the pass although the offset was far less than desired. The last orbit was once again almost directly over the A/RIA and the flight maneuver was directed by the onboard Test Conductor. The antenna azimuth position indicator was used as reference and when the spacecraft position changed slightly to the right, the pilot was asked for a "hard over turn" to the right. The aircraft was rolled to approximately 55° of bank and then back to approximately 45 to 50°. The aircraft entered initial buffet at the 55° bank angle but was easily controlled at the lesser bank angles. Altitude loss during the turn was 300 feet. The A/RIA maintained auto-track throughout the pass. A summary of Gemini XII tracking is presented in Table LV.

3.12.4.3 Ballistic Missile Mission

3.12.4.3.1 Operational Planning

Since the ballistic missile mission was one of several tests scheduled in the ETR area, all planning was directed to the total effort. The actual operational sequential schedule is shown in Table LVI. The flight pattern (see Figure 124) chosen for the A/RIA was the result of several specific test requirements rather than optimizing for a typical ballistic missile operation. The lateral approach was used to:

a. Maximize the data period.

b. Impose the maximum angular rates on the tracking antenna, particularly in the transverse axes during re-entry.

c. Present the most difficult problem of re-acquisition in the event of a prolonged black-out period.

d. Have a precise aircraft position for use in the computation of missile vs A/RIA parameters.

TABLE LIII

FLIGHT CREW COMPOSITION FOR GEMINI XII COVERAGE

<table>
<tr><th>CREW POSITION</th><th>FLT. 8 11-12-66</th><th>FLT. 9 11-14-66</th></tr>
<tr><td>Aircraft Commander</td><td colspan="2">Maj. R. Smith (AF-ETR)</td></tr>
<tr><td>Co-Pilot</td><td>Maj. R. Weaver (AF-ETR)</td><td>Maj. P. Brown (AF-ETR)</td></tr>
<tr><td>Training Pilot</td><td></td><td>Maj. R. Swift (AF-ETR)</td></tr>
<tr><td>Navigator</td><td colspan="2">Capt. R. Liberty (AF-ETR)</td></tr>
<tr><td>Flight Mechanic</td><td colspan="2">TSgt. B. Pierce (AF-ETR)</td></tr>
<tr><td>Test Conductor</td><td colspan="2">Mr. W. Price (DAC)</td></tr>
<tr><td>Flight Test Engineer</td><td colspan="2">Mr. G. Confer (BxR)
Mr. D. Rowan (DAC)
Mr. R. Moore (DAC)</td></tr>
<tr><td>MCC</td><td colspan="2">Mr. H. Piety (BxR)</td></tr>
<tr><td>Antenna</td><td colspan="2">Mr. F. Tatum (BxR)</td></tr>
<tr><td>Track and Voice</td><td colspan="2">Mr. B. Rowell (BxR)</td></tr>
<tr><td>Telemetry</td><td colspan="2">Mr. R. Hancock (BxR)</td></tr>
<tr><td>Timing/Record</td><td colspan="2">Mr. J. Walker (BxR)</td></tr>
<tr><td>HF</td><td colspan="2">Mr. K. Platt (BxR)</td></tr>
<tr><td>Observers</td><td colspan="2">Mr. D. Young (NASA-MSC)
Mr. R. Dudney (PAA-ETR)</td></tr>
<tr><td></td><td>L/Col. L. Politzer (AF-ESD)
L/Col. H. Andonian (AF-ETR)</td><td>Mr. G. Connolly (ESD)
Mr. J. Conner (PAA-ETR)</td></tr>
</table>

TABLE LIV

OPERATIONAL SEQUENCE FOR GEMINI XII

(T2 = Second Mission Take-off on 14 November 1966)

TIME	EVENT(s)
T2 - 4 days	Complete mission planning.
T2 - 3 days	Aircraft and PMEE preflight.
T2 - 2 days	First mission with GT-12 (Orbits 13, 14, and 15).
T2 - 1 day	Change mission planning in accordance with actual GT-12 mission profile. Preflight A/RIA.
T2 - 2:15	Preflight briefing.
T2 - 1:30	Papers in - A/RIA ready for flight.
T2 - 1:00	Flight crew to A/RIA.
T2 - 0:30	Observers and PMEE operators board aircraft
T2 - 0:20	Engine start.
T2 - 0:00	Take-off (1545 Z) from Tulsa.
T2 + 0:30	Establish HF communications with GFSC (Greenbelt, Maryland) via Cape Kennedy. A/RIA at 35,000 feet.
T2 + 0:32	Complete PMEE verification.
T2 + 1:20	Receive update pointing data.
T2 + 1:25	A/RIA in area of first OSP.
T2 + 1:40	Depart OSP. Receive Agena signals.
T2 + 1:44	Receive GT-12 signals.
T2 + 1:46	Downlink voice relayed to GFSC via Cape Kennedy.
T2 + 1:50	Loss-of-signal (LOS) Agena
T2 + 1:54	LOS GT-12
	Post-orbit calibration.
T2 + 3:19	Depart second OSP. Acquire GT-12.
T2 + 3:23	Two-way voice relay between GT-12 and MCCH (Houston) via Cape Kennedy.
T2 + 3:30	LOS GT-12.
T2 + 3:39	Begin VHF data dump test with Corpus Christi.
T2 + 4:12	End test with Corpus Christi.
T2 + 4:53	Depart third OSP. Acquire GT-12.
T2 + 4:55	Downlink voice relayed to GFSC via Cape Kennedy.
T2 + 5:05	LOS GT-12.
T2 + 5:24	Start VHF data dump test with Corpus Christi.
T2 + 5:39	End data dump. Depart for Tulsa.
T2 + 5:50	Teletype tests with Tulsa A/RIA (on ground).
T2 + 6:42	End tests. PMEE turn-off. Descend to landing.
T2 + 7:00	Land at Tulsa.
T2 + 7:20	Debrief.

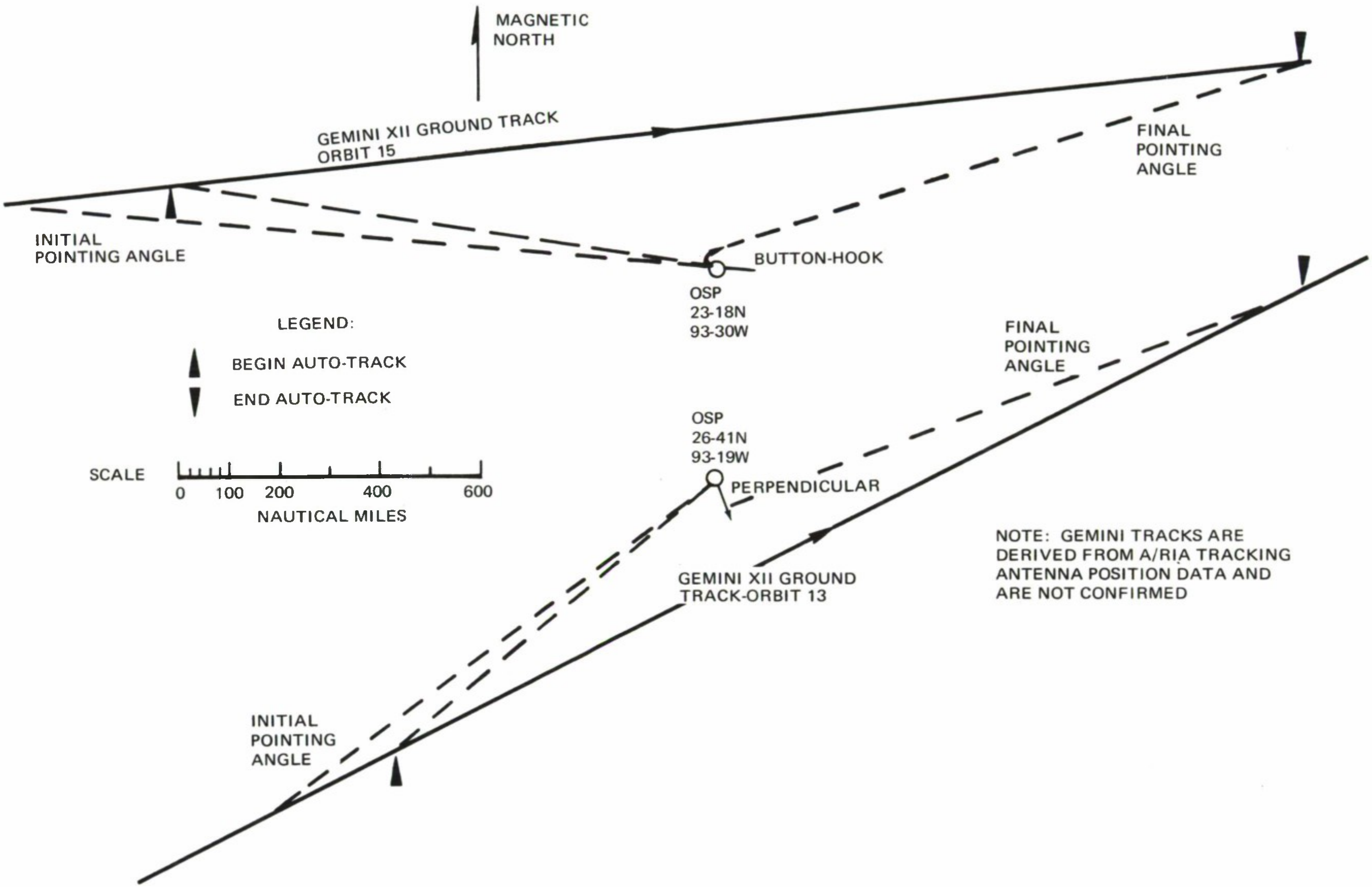


FIGURE 123. A/RIA TRACKING DURING GEMINI XII

TABLE LV

GEMINI XII TRACKING SUMMARY

Orbit	Off-Set At PCA	Flight Pattern (1)	A/RIA Turn Rate	VHF/UHF Antenna Maxima AZ Rate	EL Rate	EL	AZ	Remarks
13	160 nm	P	0	1.3°/sec	0.3°/sec	$+37^\circ$	90°R	Excellent auto track
14	210 nm	P	0	0.7°/sec	0.3°/sec	$+32^\circ$	70°R	Manual track
15	260 nm	B-H	0.55°/sec	(2) 0.1°/sec	0.2°/sec	$+25^\circ$	15°R	Excellent auto track
43	(3) -44 nm	B-H	0.72°/sec	(2) 23.7°/sec	1.45°/sec	$+103^\circ$	124°R	A/RIA turn rate was not fast enough and tracking antenna drove into azimuth limits
44	30 nm	B-H	1.75°/sec	(2) 2.6°/sec	0.63°/sec	$+74^\circ$	84°R	Good auto track
45	4 nm	B-H	2.8°/sec	(2) 15.2°/sec	1.35°/sec	$+87^\circ$	140°R	Able to maintain good auto track with high turn rate

NOTES: (1) Perpendicular (P) - A/RIA maintained constant heading approximately perpendicular to spacecraft ground track.
Button-Hook (B-H) - A/RIA remains pointed at the spacecraft.

(2) Antenna tracking rate in excess of A/RIA turn rate.

(3) The A/RIA actually passed under the spacecraft.

TABLE LVI

OPERATIONAL SEQUENCE FOR ETR TESTS
(Time 0 00 00 = Ferry Flight Take-Off)

Time D	H	M	Event
-0	13	35	Complete preflight A/RIA (including PMEE)
0	00	00	Take-off for ferry flight
0	01	50	Complete PMEE flight tests with Tulsa ground station
0	02	45	Complete TACAN flight tests
0	03	00	Land at Patrick Air Force Base
0	04	30	Briefing for ballistic missile mission
0	17	30	A/RIA ready for flight
0	17	55	Flight Crew to A/RIA
0	18	25	Observers and PMEE Operators board aircraft
0	18	35	Start engines
0	18	55	Take-off (complete mission profile shown in Figure 125)
1	02	20	Land at Patrick Air Force Base
1	03	00	Debrief mission
1	04	30	Brief for next day's test flight
1	19	30	A/RIA ready for flight
1	20	30	Flight personnel to A/RIA
1	21	00	Take-off
2	01	00	Complete data dump tests with TEL IV
2	03	00	Complete generator paralleling tests and compatibility tests
2	03	30	PMEE tests with Tulsa ground station
2	05	30	Land at Tulsa
2	06	00	Debrief flight

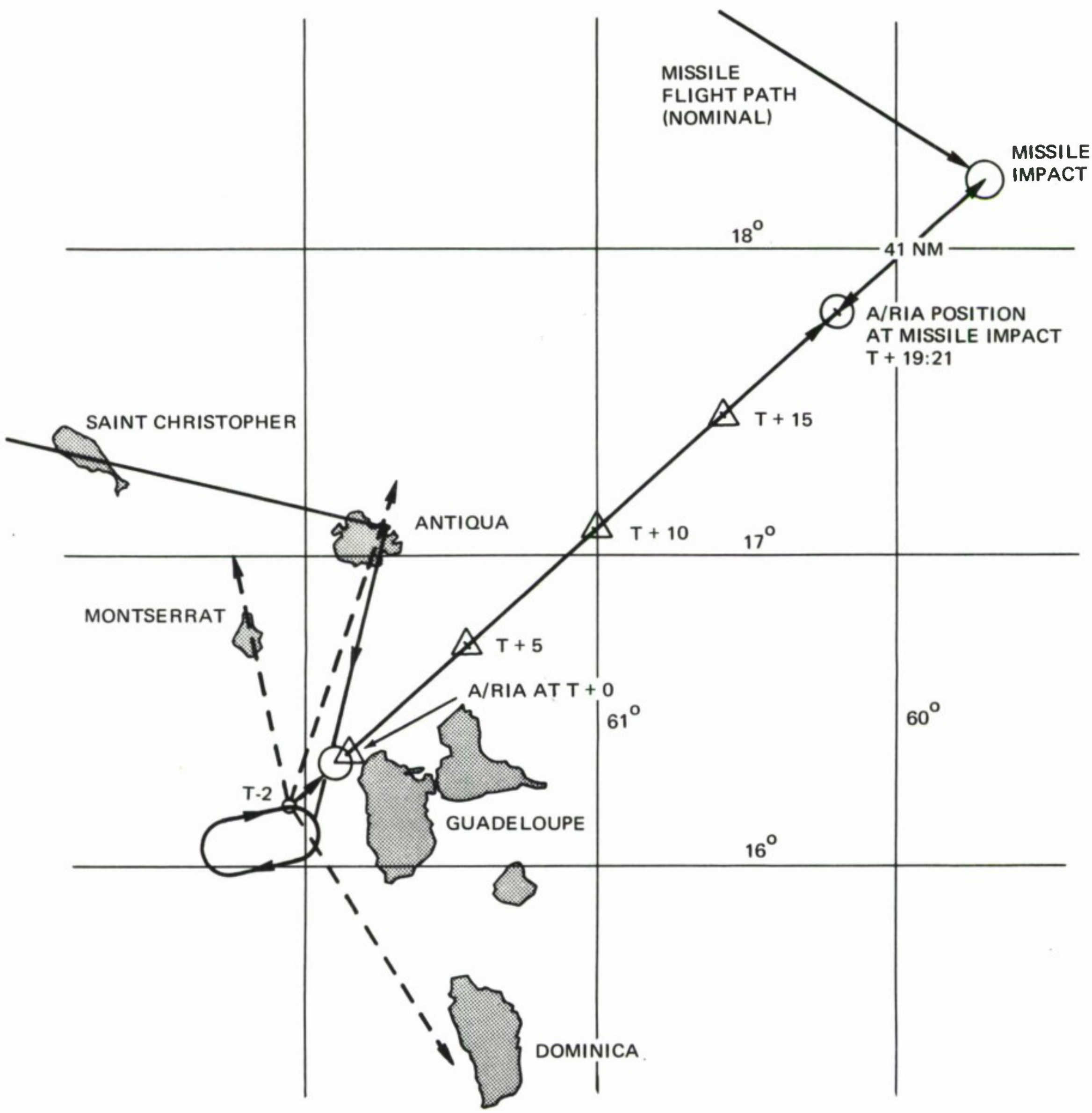


FIGURE 124. A/RIA COVERAGE OF BALLISTIC MISSILE

e. Make it possible to return to Patrick Air Force Base in the event of a hold, rather than being forced to land and refuel at Ramey Air Force Base.

3.12.4.3.2 A/RIA Mission

The A/RIA gross weight was 246,000 pounds with a cg of 25.3 percent MAC at engine start. After a water injection take-off from Patrick Air Force Base, a normal climb-out to 35,000 feet was established and the aircraft was flown down the chain of islands to a holding pattern in the vicinity of the OSP. This pattern and the departure point are shown in Figure 124.

An operational navigational problem appeared during this period of time. In order to conduct the pre-mission PMEE calibrations, it was necessary to unstow the VHF/UHF tracking antenna(1), thus depriving the navigator the use of the APN-59 radar. The necessity for an accurate aircraft position dictated alternation between the tracking antenna and the search radar. This prolonged the calibration period (an excessive amount of magnetic tape was used) and complicated the navigator's job. It is recommended that future missions limit the pre-mission PMEE calibrations to a check of receiver dynamic range, and use the post-mission period for the detailed step calibration.

The holding pattern was departed at T-2 minutes and arrival at the OSP was approximately T-20 seconds. The aircraft proceeded on course and held heading until T+22 minutes. At missile splash-down (T+19:21), the A/RIA was bearing 229°T, 41 nm ground range from the impact point. This position precluded signal deterioration caused by the trough effect (shadowing of the data signals by sea waves during the final milliseconds of missile flight).

No operational problems (other than the one cited above) were encountered during the mission. The A/RIA was landed at Patrick Air Force Base, after a flight duration of 7 hours 30 minutes, at a gross weight of 147,000 pounds (16,500 pounds of fuel remaining). The mission profile is shown in Figure 125.

3.12.5 Conclusions and Recommendations

The testing conducted in the actual operational environment, although limited, is strongly indicative of a high probability of successful mission completion. The high flight rate in the period of the ballistic missile mission (3 flights for a total of 19 hours in a 53 hour period) demonstrated the availability of the A/RIA and its subsystems. The extrapolation of test results to Apollo is conclusive that the PMEE subsystem meets its design intent. It has also been shown that the interface problems are not

(1) Sporadic signals, above receiver thresholds at the mission frequencies, were encountered with the antenna in the stow position. These signals disappeared with the antenna pointed in a south-easterly direction.

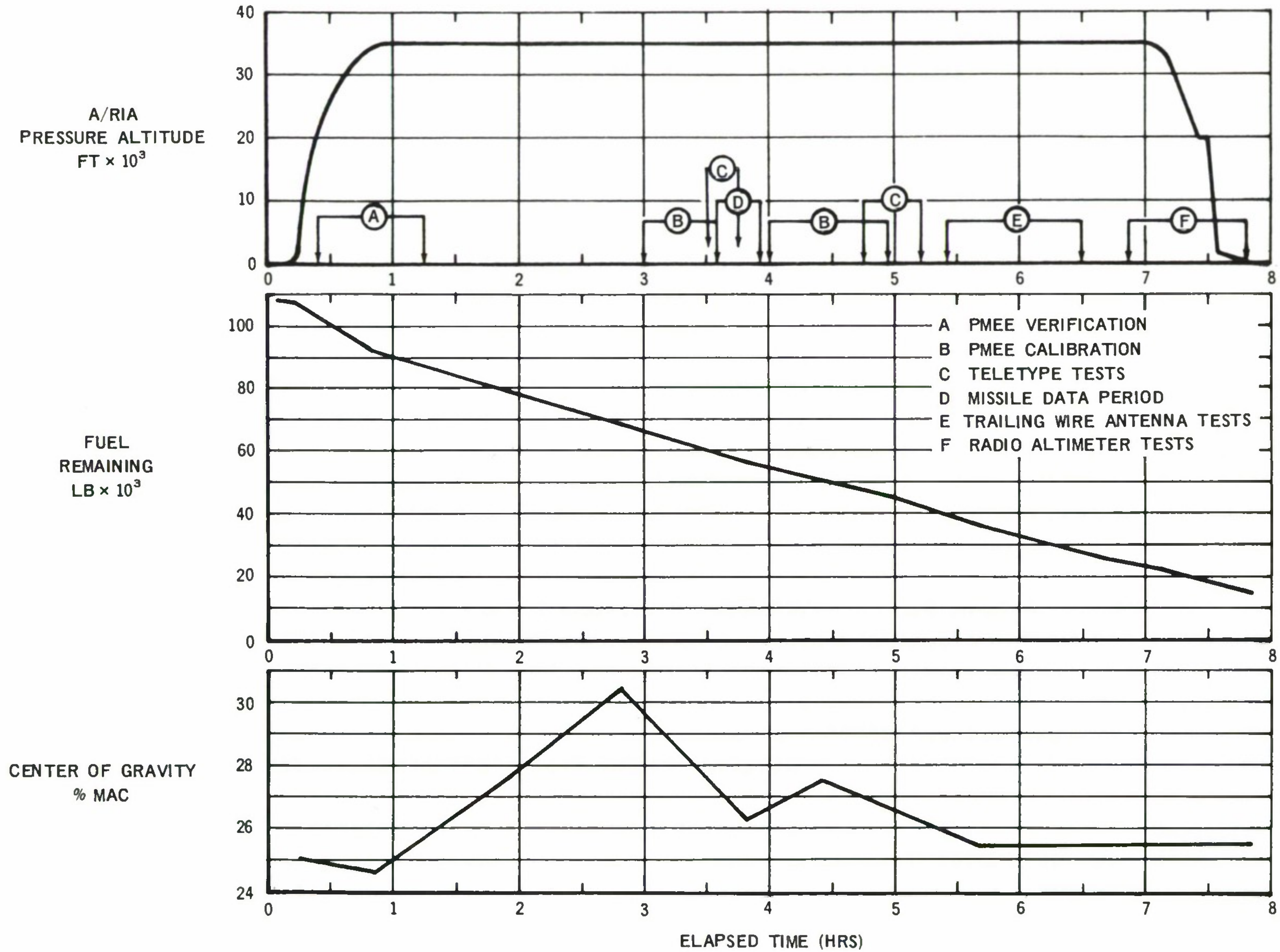


FIGURE 125. MISSION PROFILE FOR BALLISTIC MISSILE

unique and minor in nature. Recommendations that are primarily fall-outs of the operational evaluations are shown below:

a. The button-hook approach (the nose of the A/RIA is pointed at the spacecraft throughout the pass) is recommended for all orbital coverage.

b. The off-set of A/RIA to the spacecraft ground track should be 250-300 nm.

c. Re-entry vehicles should be covered from a head-on approach with the ground range at splash-down to be not more than 50 nm. The minimum range should be not less than 10 nm.

d. Coverage of initial and mid-trajectory profiles must be governed by the real-time requirements.

3.13 SYSTEM COMPATIBILITY/INTEGRATION

3.13.1 Introduction

The Category II test and evaluation of the A/RIA system was limited almost entirely to the PMEE, by the System Test Plan, Report 52931, and the Category II Test Procedures, Report DAC 56171. However, to evaluate the system operational capabilities, the results of other associated tests and Category I tests, e.g., engineering, ground, and aero-structural flight, must be considered. The purpose of this section is to summarize the results of other tests as they affect the total system evaluation, and demonstrate the compatibility of the aircraft, as modified, and the PMEE, including the compatibility of the A/RIA with other systems with which it will be operationally employed.

The complete system is described in Appendix I to this report, with illustrations of pertinent subsystems and modifications, and a summary of the composition and operation of the PMEE.

3.13.2 System Performance

The Category II test program was a true system development test and evaluation. It was the first opportunity to observe, evaluate, and develop procedures for utilization of the complete system. The aircraft itself had almost completed the first phase of aero-structural flight testing at the commencement of the Category II Program. The engineering, ground, and qualification tests of the PMEE components had progressed sufficiently in demonstration of specification compliance to permit final system integration testing on a mock-up in the laboratory. However, the Category II Program provided the first evaluation of the PMEE installed in the aircraft and flown as an integrated system.

Several problems were encountered in the system integration which might be attributed to the original concept of the system procurement (that the initial Category II testing

would be conducted concurrently with the final phases of Category I system integration testing). This concurrency requirement, which was dictated by the schedule of the Apollo mission, adversely affected the preparation of the Category II Test Procedures, the most orderly integration of the system, and demonstration of the system compatibility. The most significant problems might be summarized as follows:

a. Results of Category I testing not obtained prior to initiation of Category II testing, and so could not be used for test baselines or development of procedures.

b. Some component problems encountered in Category I testing were not revealed until late in Category II.

c. Re-testing in some areas actually made Category I extend beyond completion of Category II.

Despite the problems cited above, the original Category I integration lab tests indicated general specification compliance, and that the system would perform as expected prior to the start of Category II testing. On this basis Category II testing comprised the laboratory for complete system integration and compatibility.

The results of Category I integration testing have generally been verified in the Category II Program. In critical areas, such as signal-to-noise ratios, performance results compare quite favorably, with Category II results in some cases demonstrated to be better in the flight environment. The Category I engineering and integration tests, along with detailed system and link analyses, were used to determine the expected system performance goals, many of which were not originally specified by the system specifications. These analyses were presented as figures of merit, and used as goals for evaluation of the system performance and compatibility. Comparison of the derived goals are presented in Section II, with the details presented in subsequent sections of the report.

3.13.2.1 PMEE Performance

The preceding sections have presented the functional performance of the PMEE portion of the A/RIA system. The summary of performance compared to the system specification and test goals was presented in Section II. The Category II Test Program has demonstrated that the system can support the Apollo mission as originally specified, and that a 10-minute Apollo injection data interval can be covered by two aircraft spaced approximately 1600 nm apart. Acquisition at the horizon is predicted on UHF and VHF. Telemetry data link analyses show that an 18.4-dB SNR is expected on VHF at 1200 nm, and a minimum SNR of 8.1 dB on Unified S-Band at 900 nm. All voice links are operational and have been adequately demonstrated. The VHF and USB links are satisfactory for Apollo, and HF communications have been established at ranges up to 5500 nm. Both the UHF and VHF data dump links demonstrated adequate antenna patterns and effective radiated power.

Testing in the actual operational environment has demonstrated the A/RIA's capability to support DOD ballistic missiles as well as orbital space vehicles. Two ballistic missile missions were supported successfully during the Category II Test Program and Gemini was supported during six authorized orbits.

3.13.2.2 Aircraft Subsystems

The modifications made to the C-135A are adequate to support the PMEE without degradation to original subsystem performance. Test and evaluation of all A/RIA subsystems exclusive of PMEE, were accomplished as part of the Category I Flight Test Program. Evaluation of the aircraft subsystems was based partially on qualitative analysis of performance throughout the 170-hour Category II Flight Test Program, and partly on quantitative data collected on such subsystems as electrical and environmental control. The complete report on the subsystems is available in Vol. III of ESD-TR-67-293.

Relocation of the several antennas in the navigation subsystem, necessitated by the addition of the UHF/VHF tracking antenna and radome, has not degraded the performance of the navigation aids from the performance of the original C-135A installations. The navigation subsystems evaluated, e.g., the Radio Altimeter, TACAN No. 2, Glideslope, and Search Radar, all functioned normally. Evaluations were made on specific performance tests with data obtained for detailed analysis, and from qualitative observations of performance throughout the flight test program. Even though specific quantitative flight tests were not required on every flight, these subsystems were used and in effect evaluated on every test flight.

The environmental control subsystem, as modified, adequately performs the tasks of distributing conditioned air to all A/RIA personnel, and cooling the electronics equipment (PMEE) installed in the cabin area on both the closed and open systems. It is capable of maintaining an average compartment temperature of 70°F, within the operating limits of +20°C IRAT to -40°C IRAT. The closed system delivers cooling air to the closed-system cabinets at temperatures ranging from +32°F to +67°F, and varies as a function of the IRAT. The closed PMEE cooling-system fans are capable of single or dual-fan operation at all cabin altitudes from sea level to 10,000 feet. At high altitudes, a differential of less than 10°F exists between head and foot levels at the PMEE operator positions. The A/RIA system and the PMEE may be operated over a wide range of altitudes, which are best presented in terms of the indicated outside ram air temperatures (IRAT). The recommended upper limit is +20°C IRAT, above which an over-heat condition may arise in the PMEE closed cooling system, and the lower limit recommended is -40°C IRAT, below which the closed system supply air temperature falls below +32°F. Cabin pressurization performs as specified by the altitude schedule of T.O. 1C-135A-1, after the production installation of a small blister over the static pressure reference source.

The new electrical generating system, consisting of four brushless generators, functions identically with the original electrical subsystem in all modes of normal and abnormal power distribution. The average total electrical load is approximately 40 kw,

as the system was configured for the A/RIA Category II flight test missions. The capacity of the system is adequate to perform a basic A/RIA mission with a single generator operating; however, the loads would be marginal for one generator, and the system electrical loading would require close monitoring.

The sound pressure level measurements made during flight tests of A/RIA and A/RIA-ALOTS configured EC-135N aircraft indicate that the noise levels within the equipment compartment although higher than specified by SS 100000 will permit satisfactory accomplishment of the A/RIA mission. The sound pressure levels in the PMEE operator positions during normal cruise ranged between 89 and 96 dB (overall), with a speech interference level (SIL) of 73 to 79 dB. In the aft rest area, the overall SPL's varied from 98 to 101 dB, with SIL's from 77 to 81 dB. Although these SPL measurements are higher than anticipated, the Contractor does not feel that the cost and weight of additional acoustical installation required to reduce the levels to the design specification would be justified. The present installation is equivalent to the FAA installation and is slightly more effective in the 600 to 1200 Hz band. Speech interference level data shows that for crew stations and bunks in the aft rest area the SPL envelope is below the levels of MIL-A-8806, Section 3.1.4. A Specification Deviation (DR No. 125) is being requested based upon the foregoing considerations.

Vibration of the PMEE cabinet consoles and mounting structures was well within predictions. The most severe case during take-off with water injection-attained a maximum of 1.15 g acceleration (rms).

Other subsystems were subjected to purely qualitative observation during the test program. The lighting, intercommunications, oxygen, and emergency alarm systems were all used continuously, in normal manner, and were considered completely satisfactory in use with the A/RIA system.

3.13.2.3 Trailing Wire Antenna

The trailing wire antenna has been flown a total of 35 flights on A/RIA airplanes 1, 2, 3, and 4. Drogue deployment was made on 23 of the 35 flights. Flight test photos show that the predicted trailing antenna shape and drogue flight characteristics have been achieved. The antenna was utilized during A/RIA support of the Gemini XII and the Polaris mission. Quality of transmission and signal range have proven to be satisfactory, however, it was found the specific frequencies can drive the PMEE (UHF/VHF) tracking antenna to limits. A joint laboratory and flight test investigation of this phenomenon is in progress and will be included in a separate report.

The trailing wire antenna has posed a serious mechanical developmental problem during the flight test period. The basic problem can be resolved into the following distinct areas:

a. Separation of the drogue from the wire at or near the attachment fitting.

b. Oscillation of the drogue in close proximity to the aircraft during nesting operations.

c. Air-loads on nose of the drogue, which actuated the "Hi-Torque" circuit, thus preventing extension.

Inflight separations of the drogue from the antenna occurred at or near the drogue terminal fitting either from wire failure or inadequate termination.

All wire failures occurred during nesting operations except one, which occurred during deployment. Air turbulence near the nest induced instability in the drogue during nesting. This, coupled with lateral motion of the antenna wire when retracting, induced excessive wire bending loads during nesting.

Six types of antenna wire were evaluated, ranging from the original 1 X 7 X 0.48 copper-clad 170-lb. tensile strength wire furnished with the AS-1331/ARC-80, to 7 X 7 X 0.48 stainless steel 270 lb. wire rope.

The production configuration adopted is a 1 X 7 X 0.48 copper-clad 230-lb. wire terminating through a small coil spring device designed to reduce wire bend stress concentrations and wire fatigue. Three wire types were flown. No drogue losses were sustained while using the steel wire rope. One loss occurred with the copper-clad 230-lb. wire; however, this occurred prior to installation of the bend stress relief spring. No losses have occurred since installation of this spring device, which has now been flown on nine missions. Twelve missions have been flown since drogue loss, the last ten of which utilized the copper-clad 230-lb. tensile wire, during which 30 deployment operations were made.

A joint and concurrent laboratory test and flight test program was conducted to resolve the mechanical problems. A summary of action taken to achieve satisfactory operation is given below:

a. Soldered drogue attach terminal to prevent wire damage encountered with the swaged fitting.

b. Installation of universal joint fitting at drogue attach to reduce wire bending loads.

c. Increased reel mechanism high torque setting to provide firm nesting.

d. Development of operating techniques for stabilization of the drogue approximately 3 feet from the nest prior to final nesting (This information has been incorporated in TU 28319-0-0-1 Trailing Wire Antenna Manual).

e. Installation of improved type wire.

f. Inverted "V" nest guides to restrict lateral excursions of the drogue during nesting.

g. Modified attach hole in drogue to increase the freedom of swivel movement, thereby reducing the bending loads induced into the wire at the point of attachment.

h. Modified forward nest fairing to reduce air loads on the nose of the drogue to preclude high tension air loads during nest conditions.

i. Revised circuitry to by-pass the high torque shutoff on the antenna reel-out cycle to preclude possible oscillatory stop-start loads in the wire during deployment.

j. Decreased reel-in speed to reduce nesting impact loads. (This has also been included in TU 28319-3-0-0-1, Trailing Wire Antenna Manual.)

A complete review of the laboratory and flight test development programs can be found in two separate reports submitted to the government, DAC 56140 and DAC 56141.

The Contractor has a high degree of confidence that satisfactory system performance has now been achieved with the incorporation of the solutions outlined above; however, it would seem prudent to plan all A/RIA flights with the knowledge that whenever the aircraft utilized a trailing wire there is a possibility that a drogue loss will occur. Loss could not only be inadvertent, but could also result from intentional jettison. The operation is therefore analagous to that encountered when towing an airborne target and the problems involved in jettisoning such a target (or drop tanks, etc.), and the same operational rules should apply.

3.13.2.4 A/RIA Operational Range

Prior to the first A/RIA flights, a Contractor Letter (D80-A/RIA-66-518, dated 15 July 1966) was forwarded to HQ ESD (ESRIZ) enclosing a quantity of data concerning the operational range mission of the A/RIA EC-135N. Seven actual base facilities were coded and operational analyses were performed using the facility physical parameters and the climatology. Included herein are revised datum sheets which reflect the actual A/RIA performance as derived from the Category I Aero-Structural Flight Tests (Reference Vol II of Report ESD-TR-67-293). These revised range mission computations are included for Air Force operational planning, and are supplemental information to the final EC-135N revision to the T.O. 1C-135A-1-1 Handbook Appendix. These operational range computations are shown in Tables LVII through LIX.

TABLE LVII

EC-135N TAKE-OFF

(1) Field Code	(1) Pressure Alt.(ft)	(2) Thrust Factor	(1) OAT °C	(3) Take-Off Factor	(1)-(4) Runway Length-200	(5) Take-Off G. W. Limit
A	4850	10.87	26	26.20	9,800	217,200
B	272	12.80	30	28.58	9,800	254,500
D	11	12.92	31	28.70	8,800	245,100
N	5650	10.53	25.5	25.76	14,300	248,500
O	100	12.88	30	28.68	11,800	278,000
P	85	12.88	30	28.68	7,000	221,000
M	4300	11.10	25	26.52	6,034	179,300

NOTES:

(1) Airfield data obtained from ETR.

(2) Ref: T.O. 1C-135A-1-1 Appendix 1, Part 3, Fig. 1A3-32-4, p. 1A3-32, dated July 1967. Water injection take-off with EPR = 2.83.

(3) Ref: T.O. 1C-135A-1-1 Appendix 1, Part 3, Fig. 1A3-33-16, p. 1A3-33/1A3-34, dated April 1962.

(4) Runway length - 200 feet for turn-on. The A/RIA modification will not cause any increase in take-off distances.

(5) Ref: T.O. 1C-135A-1-1 Appendix 1, Part 3, Figs. 1A3-36-18 and 1A3-37-18, pp 1A3-36 and 1A3-37, dated November 1964.

ASSUMPTIONS: No runway gradient
Dry Runway
20° Flaps; cg at 26.0% MAC
No Wind
RSC Depth = 0 inches

(6) 2100 pounds of fuel, and 5600 pounds of water used during take-off, acceleration to 285 knots and climb to 500 feet above airport.

(7) Operating Weight Empty (OWE = 132,024 pounds).

TABLE LVIII

EC-135 ENROUTE CLIMB

Field	Start of Climb (1) Gross Wt. (Lbs)	Start of Climb (2) Fuel Remain (Lbs)	End of Enroute Climb Fuel Remain	End of Enroute Climb Fuel Used	Time (Min)	Distance NAM
A	209,500	77,500	67,100	10,400	37.0	277
B	246,800	114,800	101,450	13,350	44.8	304
D	237,400	105,400	92,550	12,850	41.0	296
N	240,800	108,800	96,300	12,500	48.5	360
O	269,800	137,800	124,850	12,950	38.2	231
P	213,300	81,300	10,400	10,900	35.8	237
M	171,600	39,600	31,300	8,300	32.3	223

NOTES & REFERENCES:

(1) Gross weight at take-off less 2100 lbs fuel and 5660 lbs of water used during take-off.

(2) Gross weight in Note (1) less 132,000 lbs Operating Weight Empty (O.W.E.).

TABLE LIX

STEP CLIMB CRUISE TO MISSION END

Field Code	Start of Cruise (1) Gross Wt. (Lbs)	Start of Cruise Fuel Remain (Lbs)	End of Cruise (2) Fuel Used (Lbs)	End of Cruise (3) Time (hours)	End of Cruise (4) Distance (NAM)	Totals (5) Time (hours)	Totals (6) Distance (NAM)
A	199,100	67,100	52,076	5.28	2375	5.9	2652
B	233,450	101,450	86,426	8.1	3643	8.85	3947
D	224,500	92,550	77,526	7.4	3332	8.08	3628
N	228,300	96,300	81,276	7.7	3464	8.51	3824
O	256,850	124,850	109,826	9.79	4407	10.43	4638
P	203,400	70,400	55,376	5.57	2505	6.17	2742
M	163,300	31,300	16,276	1.82	818	2.36	1041

NOTES & REFERENCES:

(1) Take-off gross weight less take-off fuel and water, and enroute climb fuel.

(2) Based on Category I flight test data.

(3) Fuel consumption at power setting required for 450 KTAS.

(4) Time x 450 KTAS.

(5) Cruise time plus enroute climb time.

(6) Cruise distance plus enroute climb distance.

(7) A/RIA gross weight at high key over station Operating Weight Empty (O.W.E.) = 132,024

Reserve = 15,000
Fuel Load

147,024 Lb.

3.13.3 AGE Compatibility

AGE for support of the A/RIA system was provisioned primarily as inventory or commercial off-the-shelf equipment, with a minimum of peculiar items designed specifically for the A/RIA. Operational experience during the Category II Test Program has proven this economical concept to be sound. Procurement of the commercial test equipment precluded evaluation of the greatest percentage of the actual approved AGC. However, sufficient experience was obtained with comparable equipment provided by the contractor to conclude that the approved items are adequate, and compatible with the A/RIA and its mission.

The selected and approved AGE is adequate to perform the tasks required in the preflight of the PMEE, and the necessary system in-flight maintenance, as defined in the initial concept of system maintenance. The details of the evaluation of the operational AGE as utilized in the Category II Program are presented in the AGE final report, Appendix IV. The major recommendation in the area of AGE support is, that in-flight maintenance would be expedited by the addition of four items of test equipment built into the existing consoles and equipment. Three of these, two audio generators and a VTVM, are included in ECP's 0064 and 0055, submitted to the Air Force. In addition, a built-in oscilloscope in the voice/telemetry section would greatly facilitate in-flight maintenance, as well as preclude the necessity of transporting portable equipment to the aircraft for preflight operations, and probably result in improved reliability of the oscilloscope. Test experience has shown that several equipment drawers, e.g., telemetry receivers and power supplies, may require withdrawal for in-flight adjustment. The incorporation of access holes to these test and adjustment points would facilitate in-flight adjustments.

Ground power for preflight of the aircraft and the PMEE during the Category II Test Program was supplied by Gremco 8H combination power units. In order to demonstrate the compatibility of Air Force portable gasoline-driven ground power units (MD-3 type), the B-10B unit was utilized during preflight operations. The B-10B is quite similar to the MD-3, except that the power output is only 45 kva, compared with 60 kva for the MD-3. The complete preflight was performed with the smaller equipment, with no incompatibility revealed. However, it should be noted that any gasoline-driven power unit is limited in engine operating time, which will require refueling at some time during the normal PMEE preflight operation. It is expected that the PMEE preflight will require one normal working day to perform; inventory ground power units will require refueling after approximately 4 hours of operation, which can be scheduled in the PMEE preflight sequence.

Specialized equipment is required to remove and replace the tracking antenna and radome. Its adequacy and compatibility have been demonstrated in Maintainability Category I tests, as well as during Category II evaluations. Installation, removal and exchange of the ALOTS subsystem also requires special handling equipment, which is government-furnished for the A/RIA system. For the A/RIA, the time required for an operational change has been established as 42 hours. The aircraft towbar is unique to the A/RIA aircraft, due to the radome extension to the nose. The towbar was

demonstrated to be adequate and compatible with the system. However, its operational use and carriage on the aircraft do impose some restrictions. The item weighs a total of 240 pounds, which creates some handling problems. In addition, stowage in the assigned position, in the aisle in the ALOTS area, restricts movement and operations within the area. It is recommended that the towbar not be carried on any operational mission; it should be carried only to deployment bases, and removed for A/RIA coverage of an actual mission.

Although not classified as system AGE, the aircraft boarding ladder which is normally stowed on the inside of the cargo door imposes a restriction on the movement of personnel along the aisle when the ALOTS subsystem is installed in the aircraft. It is recommended that the stowage position be changed to the wall which separates the forward rest area from the ALOTS area.

3.13.4 Personnel-Equipment Compatibility

The established elements of the PSTE program were evaluated and verified in accordance with the guidance of AFSCM 80-3, and the A/RIA PSTE Annex, Report No. TU 28325. The program, analytically performed during the Category I Program, verified the adequacy of human engineering and life support provisions, in addition to collection of the Personnel/Equipment Data (PED) file and its analysis. During the Category II Program this information was demonstrated operationally. However, there are some aspects of the personnel-equipment compatibility which are not completely defined in AFSCM 80-3 nor the program PSTE Annex. The PSTE program, through the human engineering element, verifies the capability of the individual to perform his assigned tasks with the equipment designed and provided for the tasks.

In addition to the stated objectives of the PSTE Program, considerable evaluation was made of teamwork required to properly operate the A/RIA system, and the compatibility of the team with PMEE portion of the system. It was concluded that the PMEE subsystem was separated logically into functional working areas, with specific trained personnel assigned to perform the tasks at each station. Through a separate intercommunications system in the PMEE all members of the team are tied together under the control of MCC operator, who for the Air Force is the officer in charge of the team. With minor deficiencies, discussed elsewhere, the teamwork required was demonstrated, during Category II test flights and on actual operational missions. An apparent deficiency in the team composition is the recognized need for an additional man on the PMEE crew. Actual operational missions (Gemini XII, Polaris, Athena) demonstrated the desirability of a team director, who is not tied to full-time coordination of the activities of the team console operators. Such a man should be a top-qualified system man, with full authority for aircraft positioning for optimum mission coverage, and can see the total conduct of a mission, including aircraft operations. The System Analyst could not serve in such capacity, since he is a technician/mechanic, with an AFSC of 31770. It is suggested that the man recommended should be an officer, and that he be designated the Mission Director. To serve in the suggested role, the Mission Director would require additional intercommunications control. If this concept is approved, it is suggested that consideration be given to providing the Mission

Director an intercom control box, similar to that available to the flight crew, to be located in the MCC area. Further, his earphones could be split, so that one would be tied in with the pilot, while the other would be in parallel with the MCC communications, so that he could maintain cognizance of all communications through the MCC.

The procedures used to operate the system during the Category II Test Program were not entirely satisfactory for operational application, since the test objectives and instrumentation used dictated certain procedures not directly applicable to AFETR operation of the system. The final procedures developed were a combination of the Contractor procedures used during tests, and those established in preliminary handbooks. Procedures were verified by the Air Force through participation in the test program, actual flight training missions, and assistance in coverage of an Athena missile mission. The results of the verification are reflected in changes to preliminary operating and maintenance handbooks for the system, to be incorporated in the final issue of handbooks.

3.13.5 Intersystem Compatibility

During the performance of actual operational missions, e.g., Gemini XII, Polaris ballistic missile trajectory and re-entry, and Athena ballistic vehicle, the intersystem compatibility of the A/RIA was quite adequately demonstrated. During the Gemini XII mission the A/RIA was integrated with the NASA Manned Spaceflight Network; the Polaris ballistic missile coverage was coordinated through the Eastern Test Range; and during the Athena ballistic vehicle mission, network coordination was effected through the White Sands Missile Range. During all these missions the operational compatibility of the A/RIA system was demonstrated. Communications and telemetry data collection equipment and techniques were effectively employed throughout the missions. Due to the advanced state of development of the A/RIA system, some incompatibilities with ground stations, and existing data analysis facilities were observed; these are discussed in the following paragraphs.

3.13.5.1 HF Communications

The A/RIA HF teletype system requires the use of a 425 Hz doppler correction tone. During the time interval of the Category II Program, only a second A/RIA aircraft, Bendix Radio Division at Baltimore, and ETR had the doppler correction capability to evaluate the A/RIA system. The ETR capability was added during the course of the Category II Program.

The normal configuration of the A/RIA HF subsystem which was evaluated in the program was duplex only. A non-standard configuration produced by external patching, did provide simplex operation at selected times. A simplex link capability at all times is desirable, and an ECP has been submitted for such a modification to the system.

3.13.5.2 Receiving and Recording Telemetry Data/Voice

The compatibility of the A/RIA Unified S-Band telemetry data and voice systems with the Apollo system was demonstrated through the use of the NASA C-121 Apollo Simulator. System operation was evaluated during the Milestone demonstrations and the A/RIA integrated system tests. Telemetry data and voice was received and recorded in Apollo formats, and the Unified S-Band transponder in the C-121 was successfully locked-up with the A/RIA UHF transmitter.

Telemetry data received from two DOD ballistic missiles have been successfully recorded on board the A/RIA. The only reported major problem was recording of PCM/FM telemetry from one of the missiles; the signal was tri-level PCM, and the A/RIA system had been briefed and programmed for normal binary NRZ. A comprehensive evaluation of the A/RIA performance in support of DOD ballistic missiles was not possible because required supporting information has not been received from the Government. The magnetic tapes recorded on the A/RIA during Gemini XII, the first ballistic missile, and two Category II flights have been evaluated by the government. Analysis of these data has been slowed and somewhat compromised by the following:

a. There is an apparent compatibility problem in equipment when the various agencies play back the A/RIA tapes. This incompatibility between recorder and playback is apparently common to the range network.

b. The A/RIA wideband recorders were set up for a maximum SNR on each individual channel, while the ETR practice was to set up all channels to the same level. The future A/RIA procedure should be carefully specified and governed by the directives of the using agency.

3.13.5.3 VHF/UHF Tracking

During the two ballistic missile missions and Gemini XII coverage, the A/RIA was proven to be compatible with DOD and NASA space vehicles. Tracking of one ballistic missile on VHF (P-Band) and the other on UHF (S-Band) was accomplished as predicted. Azimuth and elevation rates were well within the A/RIA capability. The maximum rate seen on the first missile coverage was 2.5 degrees/sec (elevation) during re-entry. The A/RIA tracked at rates of up to 10 degrees/sec during operations with the NASA C-121. Tracking of the Gemini XII spacecraft was accomplished successfully during all orbits where the aircraft positioning in relation to the spacecraft was reasonable. During the last three orbits covered, the spacecraft passed almost directly overhead the A/RIA aircraft.

3.13.6 Conclusions

The compatibility of the complete A/RIA system has been demonstrated, in the fulfillment of the performance requirements of the system specification, SS 100000, Section 3.1.1. Correlation of the results of the Category I and other tests required to determine the system integration and compatibility, provides adequate evidence to conclude

that the aircraft as modified, all subsystems, the PMEE, and supporting systems are capable of performing the assigned role as a complete system. Some exceptions in the area of component qualification restrict complete system specification compliance; these exceptions are being investigated and discussed with the procurement agency at the time of this report.

Support of an Apollo mission was demonstrated in both Modes I and II configuration. Operationally, the A/RIA has quite adequately demonstrated system integration, and inter-system compatibility through support of Gemini XII and ballistic missiles. Compatibility of the government-furnished ALOTS with the rest of the A/RIA was demonstrated, in addition to the revelation that the PMEE and ALOTS could in fact be employed simultaneously on a single target.

The 50 items of AGE evaluated (of the 500 recommended, 285 approved) have proven to be adequate for system support at the operating level, excluding field and depot level maintenance. The radome installation, and modifications to the navigation, communications, electrical and environmental control subsystems are compatible with the PMEE and the rest of the system. With the exception of a narrow band of electromagnetic interference (at 15 MHz) between HF transmissions on the trailing-wire antenna and the tracking antenna servo, the system RFI has been proven to be remarkably low for a system with the complexity of the A/RIA.

The functional reliability of the system has been demonstrated to be as good as anticipated. Component reliability, good maintainability, and sufficient equipment redundancy, together with consistent performance of the system, when proper maintenance and alignment procedures are used, have all contributed to faith in the capability of the system to operationally perform as specified and designed.

Comparison of the results of similar tests performed during the Category II Flight Tests and Category I Ground Tests, in critical areas such as power density at the antenna and signal-to-noise ratios, shows consistently comparable performance of the system in the two environments. Operational missions accomplished demonstrated that operational deployment of the system should expect system performance similar to that observed in the Category II Program.

3.14 ELECTRO-INTERFERENCE TEST

Flight testing of the electromagnetic compatibility of the A/RIA system consisted of evaluating the integrated system interference conditions which were specified by the Category I Test Procedures, A100284. The specific tests performed during the Category II Flight Test Program were selected, based on the ground test results, and other combinations that could not be realistically evaluated during ground tests, such as interferences from HF transmissions, antenna isolations, etc. The complete results of the Category I ground tests are reported in the Category I Test Report on Electromagnetic Compatibility, DAC-56148.

Evaluation of the ground tests revealed that the principal areas of concern in the system, which required flight testing, were responses of the HF receivers, VHF telemetry track and voice receivers, L-Band telemetry receivers, and UHF telemetry and track receivers, due to the following antenna-conducted signals:

a. Co-channel transmitter.

b. Adjacent channel transmitters.

c. Transmitter harmonics.

d. Receiver spurious.

e. Intermodulation products.

Flight evaluation of the above tests generally revealed that the majority of the ground-detected VHF, L-Band, and UHF interference conditions, due to antenna isolations, did not exist in the flight environment. Identification of all the actual receiver responses was evaluated and dispositioned by restricting usage of equipment which have secondary importance to accomplishment of the mission of the system. Specific restrictions are included in the "Recommendations" section of the Category I Electromagnetic Compatibility Test Report, DAC-56148, with a summary of such restrictions presented in Table II, in Appendix V.

Interference due to HF transmissions was generally more severe in the flight environment than during ground testing, due to the airframe effects at the HF frequencies. Operational restrictions for HF equipment, based on the test results, includes adjacent channel separation, transmitter harmonics, and second and third-order intermodulation.

The only incompatibility detected in the A/RIA system of a nature requiring corrective action, was the effect on the tracking antenna servo circuit by HF transmissions, which appeared to be more severe when using the trailing wire antenna. This incompatibility was detected during flight testing, and has not been repeatable by ground testing and simulations. This problem was resolved by the incorporation of ECP-0071 which added an RF filter to the antenna control circuitry, OA-11. The adequacy of the ECP was verified by flight test on aircraft 61-330, on 9 August 1967.

The A/RIA-ALOTS Electromagnetic Compatibility evaluation revealed no incompatibilities during ground testing, except in the following areas:

a. The ALOTS subsystem contains an intra-equipment self-compatibility deficiency which existed before installation into the A/RIA system. The photo camera drive motor degrades the ALOTS video and tracking servo system by producing spurious track points within the video tracking system.

b. HF transmissions on any HF antenna causes heavy modulation of the ALOTS video, and caused the ALOTS servo system to jitter and lose track. The deficiency occurred during ground tests for HF transmissions below 14 MHz only.

Flight testing of the A/RIA-ALOTS system confirmed the ALOTS susceptibility to HF transmissions between 2 and 11 MHz. ALOTS performance was degraded, with marginal performance, when HF transmissions were between 11 and 14 MHz, and was satisfactory for all frequencies above 14 MHz. Both system deficiencies discussed above are peculiar to the ALOTS subsystem only, and improvements to correct the discrepancies are not within the scope of this program.

The complete Electro-Interference Test Report, Data Item T-22-56.0, is submitted as a part of the Category I Final Test Report. A summary of this final report, as applicable to the Category II Flight Test Program and the system evaluation, is presented in Appendix V.

3.15 PERSONNEL SUBSYSTEM TEST AND EVALUATION (PSTE)

The basic objective of PSTE is to verify that qualified operating personnel can effectively activate, operate, maintain, and control the A/RIA system in its intended mission and/or alternate mission ground and flight environments. PS tests were conducted to insure that equipment, skills, procedures, support, and technical data adequately provide and support performance within specified constraints.

The specific Category II test objectives were:

a. Personnel Performance and Proficiency - To verify the proficiency of operational personnel, and performance of the equipment in all A/RIA system test operations.

b. Technical Orders (Procedures) Validation - To verify the technical adequacy of Technical Orders which support A/RIA system personnel performance of operations and maintenance tasks.

c. System Operational Capability - To verify the capability of the operations and maintenance crew to accept the A/RIA system at the termination of the Category II Test Program.

These objectives were achieved through compliance with the numbered tests contained in DAC TU-28325, dated January 1966, revised 25 March 1966. Exceptions to this are numbered tests 2-14, 2-17, and 2-18. It is recommended that these tests be carried out during Category III testing. (See Section IV, Maintenance Proficiency)

During Phase III, Operational Proficiency, sufficient observations were made and data collected to verify tests 2-11 through 2-15, and 2-19, and further qualified by interviews conducted by contractor personnel with Air Force operations and maintenance crews.

Test 2-16 was accomplished and verified during the technical order verification conducted at Douglas, Tulsa, during the Category II Test Program.

The complete PSTE final test report, as required by Data Item T-26-58.0-1, is attached as Appendix VII to this report.

3.16 AEROSPACE GROUND EQUIPMENT (AGE)

The system AGE requirements were originally established by analysis of the peculiar requirements of the new subsystem (the PMEE) and incorporation of these requirements with those of the basic aircraft, the C-135, which is an Air Force inventory system. One of the basic philosophies in the procurement of the A/RIA system was the utilization of commercial equipment to the maximum extent possible, to include commercial and/or Air Force inventory AGE, and commercial operating and maintenance manuals whenever available. The complete system requirements were established at the AGE Guidance Conference, including that which would be required for depot level maintenance, to be performed by the using command, AFETR.

The evaluation of the system AGE was limited during the Category II Test Program by the following factors:

a. No AGE items specified for depot level maintenance only was used or evaluated.

b. Much of the approved AGE was not available, due largely to the date of approval of the AGERD's, and lead time for procurement.

c. Substitution of contractor capital equipment for those AGE items which were not available from new procurement.

d. Substitution of contractor capital equipment for those items which are to be provided by the Air Force for maintenance of the inventory systems.

Utilization of substitute AGE during the Category II Test Program necessitated a comparison of the performance and adequacy of those items substituted with that which could be expected from the approved AGE. The results of the item-by-item comparison are presented in the AGE Category II Final Report, Appendix IV.

The tables presented in Appendix IV also code each AGE item to show the method of approved procurement, the source of the equipment used for the test program, and which items were evaluated. The tables illustrate that most of the AGE selected is standard, off-the-shelf commercial equipment, with proven reliability and maintainability. Only nine items of peculiar AGE were approved for procurement in the area of support of the aircraft. Those items approved were primarily for maintenance of the radome, antenna, oxygen, and a unique towbar for ground movement of the aircraft.

The selected substitute AGE supported the A/RIA system throughout the Category II Test Program. The tables in Appendix IV illustrate that the recommended and approved AGE, when compared by individual item, will also support the A/RIA system for

preflight, unscheduled maintenance, and general support of the system. Due to the delayed delivery of the approved AGE, the final evaluation must be delayed for the Category III Program. The AGE used in the Category II Test Program was entirely satisfactory in terms of adequacy, performance, reliability, and in terms of MTTR requirements for system maintenance.

The AGE manuals were not evaluated during the Category II Test Program, due to their unavailability during the program. This evaluation, principally of commercial manuals for the approved commercial test equipment, must be reserved for the AFETR Category III Program.

3.17 LOGISTICS SUPPORTABILITY

The concept established for support of the A/RIA system is somewhat unique, in that the aircraft is basically an Air Force inventory system, modified for the A/RIA subsystem, with a completely new electronics subsystem installed to perform the prime mission of the complete system. Logistics support for the aircraft subsystem is unchanged, except for the relatively minor modifications made to the electrical and environmental control subsystems. The PMEE was designed to a great degree around existing commercial equipment, and integrated into a system capable of performing the space surveillance mission. Due to the relatively few systems procured by the Air Force, the full responsibility for maintenance and support of the system was assigned to the using command, AFETR. The concept of system support was outlined in the Douglas proposal document, "Logistics Support Program," Report No. 52923.

3.17.1 Supply Support

Supply support of the system involved and adjustment/review of Air Force stock levels for the basic aircraft, determination of requirements for unique spares for the aircraft modification subsystem, development and verification of spares requirements for support of the electronics subsystem, and determination of the requirements for AGE to support the system. Basic guidance in the selection of spares and AGE included the utilization of standard Air Force inventory items insofar as possible, and commercial off-the-shelf equipment and manuals, with unique spares and AGE kept to an absolute minimum. The concept of spares provisioning was established in a Statement of Provisioning Policy on 5 November 1965.

The original concept of system deployment and resultant supply support requirements, involved a two-base system deployment. However, during review of Production List 08 on 17 October 1966, the concept was altered to a fourbase concept, which necessitated some adjustment in spares provisioning. As a result all production lists were reviewed and altered at that time.

Recommendations were made for two different kits for operations away from the home base, Patrick Air Force Base. Kit "A" would include adequate spares for support of eight A/RIA systems for a 30-day period of approximately 100 flight hours per aircraft. Kit "B" would support four systems for the same time and flight hour rate.

The approved production lists reflect the final recommendations for in-flight spares kits, with one kit to be provided for each aircraft. These spares are considered adequate to support the system for 50 flight hours, over a 15-day period. The kit is limited to components which can be installed in flight, with no soldering or disassembly of components required. An exception is the inclusion of a spare cartridge starter, which is carried in case of failure of a starter at a remote base.

Component failures and the consumption of spares were monitored throughout the Flight Test Program, involving 417:50 flight hours. The procedures outlined in AFM 66-1 were used in the collection of failure and spares consumption data. A summary of the failures which occurred during the Flight Test Program is presented in Appendix VI, Reliability/Maintainability Category II Test Report. Final recommendations for adjustments to the production lists were made to the Air Force, based on analysis of the data collected and system performance. The levels of depot spares recommended are based on the same data; however, verification of the adequacy of the levels must be postponed until the Category III evaluation by the using command, AFETR, who will also be responsible for depot-level maintenance of the system.

3.17.2 Maintenance

The established concept of maintenance of the PMEE is based on the performance of the majority of the subsystem maintenance by the operators. These tasks include preflight of the system prior to a mission, removal and replacement of components, and in-flight maintenance, also restricted to removal and replacement. Repair of replaced components will be accomplished by a specialized repair facility for the PMEE, manned and operated by the using command. The maintenance functions served by the facility will in effect encompass the tasks normally assigned to both field and depot level maintenance organizations in the Air Force. The PMEE maintenance organization at AFETR has been altered somewhat from the original concept which was presented in Report 52923. Originally a single organization was programmed, with both the PMEE operators and maintenance personnel assigned. Reportedly, the evolved concept entails a separate maintenance organization, responsible for component repair, with the PMEE operators assigned to the AFETR Aircraft Operations Division. This splitting of maintenance responsibilities, e.g., PMEE preflight and component repair, may produce some deficiencies in provisioning for system AGE, some of which will be required for both preflight and repair. Such an evaluation will necessarily be required by AFETR during the Category III Test Program.

3.17.3 Transportation Modes

Determination of the methods of shipment and movement of the PMEE was assumed by the Air Force; therefore, the contractor participation was limited to providing the weight and cube of the items provided by the contractor, which was accomplished early in the program. Centralized assignment of the aircraft and all logistics support at a single base, i.e., Patrick Air Force Base, simplifies the normal problems of packaging and transportation.

3.17.4 Aerospace Ground Equipment

The requirements for AGE for support of the A/RIA system were developed with the philosophy of using Air Force inventory test equipment insofar as possible, which has resulted in a very short list of peculiar AGE for the A/RIA system. The AGE recommended is discussed in detail in Appendix IV, along with an evaluation of the contractor capital stock equipment generally used in lieu of the recommended items, which in most cases is to be provided by the using command. The AGE has proven during the Category II Test Program to be adequate to support the system as programmed. Three items have been determined to be desirable as installed test equipment in the aircraft, for preflight and in-flight maintenance and calibration. These items are enumerated in Section IV, Recommendations.

3.17.5 Technical Manuals

A total of 217 Technical Orders/Manuals are required for the operation and maintenance of the A/RIA system. Of this total, 38 are associated with the aircraft, either as new publications, partial, or supplemental editions of existing Technical Orders. The PMEE subsystem requires 105 manuals, of which 41 are new publications, 32 commercial, 22 up-dated commercial, and 10 are existing or supplemented Technical Orders. The approved AGE requires 74 manuals, 6 of which are required for PMEE AGE, 67 are commercial manuals, and one is a supplement to an aircraft Technical Order. The new and partial manuals required validation and verification; validation was accomplished on the 0/MTU at Bendix, Towson, and Patrick Air Force Base, and Air Force verification was accomplished at Douglas, Tulsa, in February 1967, during the Category II Test Program. The results of the validation and verification will be incorporated in the formal manuals, scheduled for delivery to the Air Force in August 1967.

3.18 RELIABILITY/MAINTAINABILITY

The objective of the R/M demonstration conducted during the Category II Test Program was to verify system hardware performance in an environment as near as possible to that which the system will be subjected in operational usage. A sample size of three was selected because of the production availability of the first three aircraft during the Category II Flight Test Program. The results of the R/M demonstration tests are summarized in the following sections. The complete report of the tests is presented as Appendix VI.

3.18.1 Reliability

The Category II reliability demonstration testing commenced with the first flight of aircraft 1 with a full compliment on board, on 28 October 1966. The demonstration was based on a sequential test plan, outlined in Report 52928, and in accordance with ESD-TDR-64-616, "Reliability/Maintainability Handbook," and the Category II Flight Test Procedures, Report No. DAC 56171. The significant parameters governing the accept/reject criteria are as follows:

MTBF = 50 hours

Truncation time = 310 hours

Maximum number of failures allowed = 10

Customer risk = 10%

Contractor risk = 10%

Discrimination ratio = 0.438

The above parameters result in the following accept/reject equations. These equations put in chart form are as shown in Figure VI-1, in Appendix VI.

Accept Curve

$$F_A = 9.03226\,t - 2.6515$$

Reject Curve

$$F_R = t + 2.6515$$

From the time of the first flight, all flight hours accumulated on aircraft 1, 2, and 3 with a full compliment of operational PMEE on board were counted as test hours. Likewise, from the same point in time, all valid failures were charged to the system. A valid failure was defined as a failure of any component of the subsystem that would result in a mission abort or significant degradation of mission capability. Failure data were derived from Failure and Rejection Reports, Test Failure Reports, and A/RIA PMEE Log Books.

Eight PMEE in-flight failures and one aircraft modification in-flight failure occurred during Category II flight operations. All of these failures were analyzed and scored as valid or invalid, based on the aforementioned definition of a valid failure (ref. Table II in Appendix VI).

One valid failure occurred after 8.3 hours of flight testing (the airflow interlock vane in the PMEE cooling subsystem jammed, which resulted in a false indication of airflow). The failure was analyzed, and a design change resulted. All other in-flight failures were scored as invalid, based on the redundancy built into the system, and capability to complete the assigned mission. The system reliability demonstration was completed on 21 January 1967, after 113 hours of flight testing.

Since slippage in the Category I reliability demonstration test schedule caused the Category I versus Category II sequence to essentially be reversed, all failure data occurring in Category II ground and flight operations were analyzed, and used to define potential problem areas in the Category I reliability demonstration.

3.18.2 Maintainability

The demonstration of the system MTTR does not fall exclusively under either Category I or Category II; hence, some data for PMEE MTTR were accumulated during Category II testing. All data to demonstrate the MTTR of the aircraft modification subsystem were accumulated during Category II testing on an as-failed basis. The reason for demonstrating the MTTR of the aircraft modification subsystem in this manner was because of the agreed philosophy that no failures would be induced into equipment while installed in the test aircraft. Analysis of the maintainability data for the aircraft modification subsystem yields an MTTR of 0.951 hours, as measured against a requirement of 1.36 hours. The MTTR demonstration for the PMEE was accomplished at Bendix Radio Company, under the Category I Test Program. The results will be reported in subsequent reports.

3.19 SYSTEM SAFETY ENGINEERING

Evaluation of system safety was continued throughout the Category II Test Program, as a portion of the complete system safety engineering program, in accordance with the program defined in the System Safety Engineering Program Plan, Douglas Report No. 52932. The areas of primary interest concerning system safety were the aircraft modification (electrical subsystem changes, aerodynamic changes associated with the airframe, radome, and antennas, the environmental control subsystem, and emergency egress procedures) and the PMEE installation (equipment mounting, cooling, operator positions) and the operation of the PMEE itself.

The flight characteristics of the aircraft were basically unchanged by the addition of the extended nose and the radome; neither did the addition of the ALOTS pod materially affect the handling characteristics of the aircraft. The complete results of the Category I aero-structural flight test program are reported in a separate report, ESD-TR-67-293. The center of gravity, and lateral, directional, and longitudinal stability of the EC-135N do not differ appreciably from the basic C-135A. From a system safety standpoint, the aircraft modification has been adequately demonstrated.

The other major aircraft subsystems modified in the aircraft (the electrical, environmental control, and navigation subsystems) were all evaluated, as a part of the Category I Subsystem Flight Test Program, during the Category II Test Program. The results, which will be reported separately, indicate that no degradation in system safety has resulted, and that all the safety design requirements have been satisfied.

Development of the trailing wire antenna produced some safety problems, in that three drogues were lost in flight. Improvements in the drogue attachment, increased wire strength, modification of the nest and fairing, and development of safe operating procedures for employment have produced a safe system. This has been demonstrated during the latter phase of the Category II Test Program.

Emergency procedures, including emergency egress on the ground and in flight, ditching, and decompression, were developed and reviewed during the test program. The

results and coordinated procedures are published in the system Technical Orders. Applicable checklists and procedures were verified during the Category II Test Program.

Results of the vibration tests conducted on the UHF/VHF tracking antenna and mounting of the PMEE consoles indicate that no safety problems exist in this modification. Equipment racks and operators' seats have been designed to tolerate acceleration loads which might be encountered during emergency landings and ditching.

Operating and maintenance procedures were observed and evaluated throughout the Category II Test Program, with several resultant actions and recommendations. The results of the system safety engineering program are summarized, and presented in Appendix VIII.

SECTION IV

RECOMMENDATIONS

4.1 GENERAL

Recommendations contained herein present the system recommendations made as a result of the Category II Test Program. Associated tests and Category I tests were considered, as those results affected the total system evaluation. For convenience, the recommendations are segregated by area of interest or origin. Some recommendations, if accepted, would require additional Air Force funding under ECP's submitted; others would require independent Air Force action or procedural changes. It is suggested that the cited recommendations be evaluated by the Air Force in the system Category III Test Program.

4.2 EQUIPMENT IMPROVEMENTS

The following recommendations are made for improvements in system equipment:

a. ICS Station Adjacent to OA-20 and OA-21

An additional intercommunications system control box in the OA-20/OA-21 area would greatly facilitate the set-up, preflight, and in-flight adjustments of the equipment used by the HF and timing/record operators.

b. Time Displays at Navigator's Position

GMT and Countdown/Elapsed Time Displays are recommended for the navigator's station for precise flight crew coordination of the A/RIA mission requirements. An additional remote station, similar to those used throughout the PMEE and driven by the timing subsystem, is recommended for this installation.

c. MCC Audio Tone for Intercom Warning

The MCC cannot contact the flight crew (other than on "CALL") unless the Pilot's selector is in the "PMEE" position. The HF operator is also difficult to contact because of the operational necessity of reducing intercom volume while working HF. The addition of a separate audio tone circuit for MCC use would provide a discrete signal for intercom warning. It is recommended that the modification be incorporated in the form of a momentary switch for the tone and a 3-position selector switch for "Pilot," "HF," or "Intercom Select." The first two positions would by-pass the receiving station selector setting and would allow the tone to be heard directly by the Pilot or HF operator. The third position would connect the audio tone circuit to the normal intercom selector for any select station distribution.

d. New Intercom Control for MCC

The intercom control at the MCC position could be improved by replacement of the present rotating selector switch with a push-button control, lighted as most of the PMEE control switches. The present rotary switch is time consuming and subject to human errors. The MCC becomes quite occupied during a mission; the recommended push-button control would greatly expedite his communications, and reduce the possibility of error in station selection.

e. Lighting in Radome

It is recommended that brighter or additional lights be provided in the radome for use during maintenance or preflight activity.

f. Radio Call Placard

It is recommended that radio call placards be installed at the MCC and HF operator positions. A small frosted plastic panel should be installed with the placard for operational information. It is suggested that such an installation could be locally fabricated by the using command.

g. Fasteners for Receiver Covers

Replacement of the receiver cover attachment screws with captive fasteners would expedite cover removal, and facilitate maintenance. The number of such fasteners should be commensurate with the requirements for bonding.

h. HF Simplex Capability

Recommend that the HF subsystem be modified to provide a simplex capability. The duplex-only configuration, used during Category II testing, limited HF communications due to operational limitations of the range nets. Simplex operation could be provided with the incorporation of ECP 0057.

i. Recording of Timing Code

ETR has recommended that the wideband recorder be modified so that a GMT timing code could be recorded simultaneously with other data on any or all selected tracks. (The code could be 12 dB down.) This modification is particularly desirable for timing correlation during Data Dump operations.

j. Receiver Lock Indicators

The addition of tracking receiver lock indicators at the Voice/Telemetry operator positions would assist the operators and reduce intercom traffic. These indicators would parallel those in the MCC position.

k. Autotrack Indicators

In addition to receiver lock indicators, an indication to the Voice/Telemetry operators of system AUTOTRACK operation would aid mission efficiency.

l. HF Receiver Squelch Circuit

The addition of a squelch circuit in the HF receivers would improve intelligibility during uplink operations. The present configuration allows bursts of noise in the receivers to be re-transmitted. This modification is included in ECP 0057.

4.3 PMEE PROBLEMS AND RECOMMENDATIONS

Several problems were revealed during the conduct of the Category II Test Program. Some were resolved through appropriate engineering action with retesting, some resulted in ECP action or request for approval of such action, and some are as yet unresolved. The PMEE problems are enumerated below, with a brief discussion of the action taken, or recommendations for their resolution:

a. Receiver Phasing (Discussed in Paragraph 3.4.4.1)

Ground phasing of the tracking receivers with the collimation tower requires special equipment which was recommended as system AGE, and rejected by ESD.

Action Taken

An improved alignment technique has been inserted in the manuals to alleviate this problem. Sections have been re-written and inserted in TU-28319-2-2, and the RF preflight procedure.

b. Signal Data Demodulator Unlocks Intermittently (Discussed in Paragraph 3.5.5.1)

The data demodulator VCO has been unstable during flight, causing intermittent unlocking.

Action Taken

Investigations at Bendix Radio have shown that the VCO is within specification and Category I ground test results support this conclusion. The apparent reason for observed in-flight instability of the SDD is a complex combination of ambient temperature in the unit, and the warm-up time required to achieve oscillator frequency stability. The problem is under continuous investigation through correspondence with ESD.

c. HF Transmissions Affect UHF/VHF Antenna Servo (Discussed in Paragraph 3.4.4.3)

Frequencies in a narrow band at 13 MHz transmitted by the trailing wire antenna adversely affect the servo system and drive the UHF/VHF antenna off target.

Action Taken

This problem is under investigation by the contractor and the resolution will be reported in subsequent reports.

d. No Means for Recording VHF Voice Receiver AGC's (Discussed in Paragraph 3.6.12.1)

In the present configuration, VHF voice receiver signal strength cannot be recorded on the wideband recorder. This recorded data may be extremely valuable for Apollo post-mission analysis.

Recommendation

It is recommended that ESD request an ECP to provide that the VHF voice receiver AGC be cabled to the RF patch panel, and jacks be provided for patching the RHC and LHC voice AGC into the data multiplexer.

e. No Parallel Jacks on RF Patch Panel (Discussed in Paragraph 3.6.12.2)

The lack of parallel jacks precludes the patching of TLM data outputs to both wideband recorders simultaneously. At present, VHF and UHF uncombined voice cannot be recorded when the voice combiners are patched to the receiver outputs.

Recommendation

It is recommended the ESD request an ECP to provide that parallel jacks be provided on the RF patch panels.

f. Wideband Recorder Level Setting Difficult to Make (Discussed in Paragraph 3.6.12.4)

During the Category II tests, data was degraded on several occasions because the wideband recorder record levels were not set up correctly.

Recommendation

It is recommended that ECP 55 be approved. This ECP provides a VTVM and oscillator in the record section to provide a means of calibrating the VU meters on the inputs of the record channels and a means of presetting record levels in flight.

g. Excessive WOW and Flutter, Low SNR on Pemco Audio Recorder (Discussed in Paragraph 3. 6. 12. 5)

During the Category II test, considerable data recorded with the Pemco Recorder was of poor quality because of excessive WOW and flutter and a poor SNR.

Action Taken

This problem is being corrected by the manufacturer and Bendix Radio as a compatibility change. Bendix has designed a 300-Hz-to-3 KHz, 18-dB-per-octave bandpass filter that will be installed in the audio coupler. Tests run at Bendix Radio indicate that this filter will improve the SNR by 12 dB. The recorders are being returned one at a time to the manufacturer for extensive rework.

There is also an interface problem between aircraft prime power and the record group. Aircraft power is governed by specification MIL-STD-704, which allows 3 vdc peak-to-peak ripple. Contractor improvements to the +28 vdc prime power quality and the resulting effect on audio SNR will dictate whether further improvements are required for the line filter.

h. High Noise on VHF Voice Receive Link When Not Receiving Carrier (Discussed in Paragraph 3. 6. 12. 6)

A high noise level exists on the VHF voice receive link when carrier is not being received.

Recommendation

It is recommended that the squelch modification as described in ECP 0057 be incorporated.

i. HF Voice Combiner Will Not Combine Frequency Diversity or Sideband Diversity Signals (Discussed in Paragraph 3. 8. 7)

Tests have shown that the HF voice combiner will not satisfactorily combine frequency diversity or sideband diversity signals.

Recommendation

It is recommended that the HF combiner be replaced by a diversity selector. A selector would provide protection against short term frequency fades, and would also permit frequency diversity reception. The theoretical SNR improvement gained by a combiner is substantially undetectable by the human ear with the present configuration.

j. Data Dump of the Unified S-Band 1.024 MHz Subcarrier (Discussed in Paragraph 3.9.7)

Several ground tests proved that upon playback of the recorded subcarriers the USB data demodulators would not lockup on the post-recorded subcarrier perturbed by incidental FM and PM resulting from recorder operation.

Recommendation

It is recommended that the Unified S-Band demodulated data be recorded and dumped in PCM/FM mode.

k. The TR 109 and MR 109 Receiver Tuning Meters Stick After Being Pegged

This pegging and subsequent sticking occurs often during the auto-search mode. This prevents monitoring of receiver tuning.

Recommendation

It is recommended that paralleled reversed diodes in shunt with the meter movement be incorporated. Since the critical zero area is center scale, the logarithmic compression of the maximum deflection to approximately half scale (either side of zero) would not pose any operational problems.

l. Sneak Circuit in MCC Panel Lights When Circuit Breakers are Pulled

Partial illumination of the Master Control Console occurs when the MCC power switch is open, the receiver group power switch is closed and the Receiver Group relay contact open.

Recommendation

If this problem is considered detrimental to system operation, an improvement ECP will be submitted to incorporate isolation diodes on the indicator lights.

4.4 TEST EQUIPMENT AND PROVISIONS

The AGE recommended for system maintenance has been demonstrated to be adequate; however, additional built-in test equipment would greatly facilitate performance of the PMEE preflight, as well as in-flight maintenance. The following recommendations are submitted as improvements in this area:

a. Addition of Audio Generator in HF Operator Position

Recommend approval of ECP 0064, which would install an additional variable audio generator at the position as on-board test equipment. This modification would reduce set-up and trouble shooting time.

b. VTVM and Oscillator at Record Position

Recommend addition of a VTVM and oscillator (audio generator) in the Record Section, to provide a means of calibrating the VU meters on the inputs of the record channels, and pre-setting record levels. These additions to on-board test equipment are included in ECP 0055.

c. Oscilloscope in Voice/Telemetry Section

Recommend the addition of an oscilloscope in the Voice/Telemetry Section, as built-in test equipment. This would expedite preflight operations, and obviate the requirement for transporting portable equipment, presently used for preflight tasks; in addition, it would be available for in-flight maintenance.

d. Access Holes for Test Adjustments

Provision of access holes in the top covers of the AC and battery power supplies would permit adjustment and test point checks without removal of the covers. Consideration should be given to access holes for adjustments on the DEI receivers.

4.5 PERSONNEL SUBSYSTEM

The following recommendations are submitted in the personnel subsystem:

a. Additional Man for PMEE Crew

Recommend consideration of an additional man for the PMEE crew. Experience during actual operational missions (Gemini XII, Polaris, Athena) has demonstrated the desirability of an additional operational, top-qualified system man. This would be in addition to the presently programmed System Analyst, who is primarily a technical/mechanic. The proposed addition could be called a Mission Director - one who would have cognizance of the overall conduct of the mission, and would have full authority for aircraft positioning, maneuvers for target coverage, and coordination between the pilot and the PMEE crew. Operational experience has shown that the MCC is too occupied in the coordination of the activities of the PMEE operators to serve effectively in the capacity of the Mission Director.

b. Tracking Antenna Status Lights for Pilot

Recommend a change in the present status indication to the aircraft commander. This change would present the antenna status of "LOS", "Manual", and "AUTO" track. The lighting of these indicators should be made independent of the normal instrument lighting. The inclusion of these indicators would give the Aircraft Commander significant information required for aircraft maneuvers during an A/RIA mission.

c. Additional ALOTS Operator Life Support Equipment

The ALOTS subsystem was designed for one console operator, and one operator for the manual tracking station (MTS). However, AFETR currently uses either two or three additional personnel in the operation of the console. Provisions should be made for emergency oxygen and intercom tie-in for the additional personnel. In addition, the seat belt provided for the MTS operator was observed to be too short, when the normally used thick cushion is placed in the seat. The configuration of the MTS apparently requires the use of such a cushion, in order for an average-size operator to properly use the sight. Any change made to the intercom controls at the ALOTS console operator position should include relocation of the present console control box to the bulkhead immediately to the right of the console. This would facilitate inclusion of intercom connections for additional operators, and reduce noise in the intercom, observed in the ALOTS console and equipment.

4.6 SYSTEM SAFETY

System Safety Engineering, plus general PSTE observations during the ALOTS compatibility test flight, provided the following recommendations concerning system safety:

a. Cargo Door Braces

Cargo doors should be supplied with braces to hold them in the up (open) position. These could either be fabricated by the using command, or be provided as additional AGE.

b. ALOTS MTS Operator Safety

The GFE seat belt provided for the MTS operator should be lengthened if the enlarged cushion is continued. Operators should also be cautioned to keep the belt fastened at all times while in the tracking station. Also recommend the addition of a tether for the operator, to be attached and worn while assuming his position in the seat of the MTS, prior to fastening his seat belt. Greater security from possible decompression would also be obtained by the addition of a shoulder harness to the seat belt.

c. Grounding of Aircraft

Maintenance personnel should be cautioned about the absolute necessity for providing a complete ground of the aircraft, during preflight of the PMEE. Experience has shown that if the ground connection is inadequate, actuation of the HF communications subsystem will create a hazardous condition for maintenance personnel working in the aircraft. Recommend that frequent checks to verify the adequacy and resistance of installed grounds be made at any A/RIA operating base prior to and during PMEE operations.

d. Grating Over ALOTS Bubble

Recommend installation of some sort of a grating over the ALOTS bubble opening, when the ALOTS MTS is removed, to preclude extraction of personnel in case of loss of dome and resultant decompression. Such a device could be fabricated by the using command.

4.7 PROBLEMS UNRESOLVED

The following problems exist in the A/RIA system at the completion of the Category II Test Program. They are in various stages of investigation and resolution, with no recommendations at the time of this report. Findings and final actions will be transmitted by separate correspondence.

Cooling air supply temperatures to PMEE cabinets are lower than predicted.

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13. ABSTRACT The A/RIA system is designed to provide voice and telemetry data communication with Apollo and other spacecraft, with a capability to relay all communications to the Manned Spaceflight Network, and record all telemetered data on board. The system includes a basic C-135A aircraft, modified to accept and support the electronics equipment and automatic tracking antenna required to perform the mission. The purpose of the Category II flight test program was to verify that the system could acquire and track an orbiting space vehicle--and trajectory of ballistic missiles--using VHF, UHF, and Unified S-Band frequencies, with simultaneous recording and two-way voice link with ground stations via HF. Quantitative system testing was performed at Douglas Aircraft, Tulsa, Okla.; operational evaluations included coverage of Gemini XII, a Polaris ballistic missile, and simulated Apollo coverage through use of a NASA C-121 Apollo Simulator. Tests demonstrated system capability to acquire and track an Apollo vehicle at the radio horizon, a range of approximately 1200 nautical miles on VHF, with an expected data bit error rate of 1×10^{-4} in the data link. On the Unified S-Band, the expected range is 900 nautical miles, with an expected data bit error rate of 1×10^{-4}. HF communications have been demonstrated at ranges up to 5500 nautical miles, using simplex, duplex, single sideband, independent sideband, frequency diversity, and sideband diversity. Extrapolation of the test results to the expected operational performance of the Apollo spacecraft indicates that the A/RIA system will fulfill the design requirements, and perform its assigned mission.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
A/RIA--Apollo Range Instrumented Aircraft						
ALOTS--Airborne Lightweight Optics Tracking System						
EC-135N--Designation of A/RIA-modified C-135A						
PMEE--Prime mission electronics equipment--on A/RIA						
OSP--On-Station Position (of aircraft)						
Unified S-Band						
Rate memory						
UHF/VHF Tracking Antenna						
Data dump						